REPORT NO. FRA/ORD-78/47

MATHEMATICAL MODELING OF DODX RAILCARS

Engineering Test and Analysis Division ENSCO, Inc.
Alexandria, Virginia 22303

FEBRUARY 1980
FINAL REPORT

Document is available to the public through
The National Technical Information Service,
Springfield, Virginia 22161

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Freight Systems
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No.	FRA/ORD-78/47
2. Government Accession No.	
3. Recipient's Catalog No.	
4. Title and Subtitle	MATHEMATICAL MODELING OF DODX RAILCARS
5. Report Date	February 1980
6. Performing Organization Code	
7. Author(s)	C.T. Jones
8. Performing Organization Report No.	DOT-FR-77-20
9. Performing Organization Name and Address	Engineering Test and Analysis Division ENSCO, INC. 2560 Huntington Avenue Alexandria, Virginia 22303
10. Work Unit No. (TRAIS)	
11. Contract or Grant No.	DOT-FR-64113
12. Sponsoring Agency Name and Address	U.S. Department of Transportation Federal Railroad Administration 400 Seventh Street, S.W. Washington, D.C. 20590
13. Type of Report and Period Covered	Final Report 10/75 - 6/77
14. Sponsoring Agency Code	
15. Supplementary Notes	

16. Abstract

This report presents the results of a project conducted to determine the roll stability characteristics of large capacity freight cars, 100 to 200 ton, loaded with high center of gravity containers. The model, obtained from AAR, is a 22 degree-of-freedom, non-linear, time domain model of railcars equipped with two axle trucks. The model was modified to include hydraulic dampers, an improved Coulomb friction damping model, and a track input to simulate perturbed track specified in AAR specification D-65. Also a lower order integration technique and a larger integration stepsize were employed to reduce computer run time.

The model was validated against each of four vehicles on which full scale field tests had been conducted. In three of the four cases sufficient agreement was found between the results of the model and those of the field test to proceed with further simulations of other load/suspension configurations. Results of these simulations suggest that improvement in roll stability can be achieved by reducing the vehicle suspension spring rate or similarly increasing the load. It was also found that one of the vehicles studied possessed a dead band in the stroke of the hydraulic stabilizer. By modifying this stabilizer to operate over the full stroke, vehicle dynamic performance should show improvement.

17. Key Words	Computer Simulation Mathematical Model Roll Stability Wheel Lift Derailment Tendency DODX Flat Cars
18. Distribution Statement	Document is available to the public through the National Technical Information Service, Springfield, VA 22161
19. Security Classif. (of this report)	Unclassified
20. Security Classif. (of this page)	Unclassified
21. No. of Pages	168
22. Price	

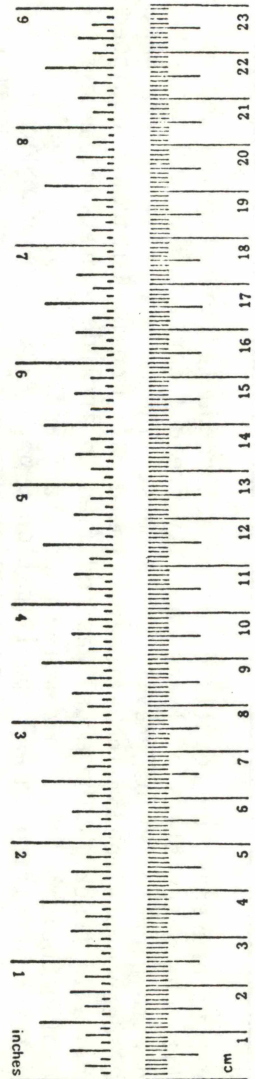
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

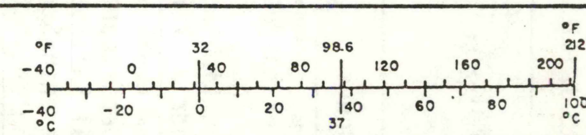


TABLE OF CONTENTS

Section	Title	Page
1.0	Introduction	1-1
	1.1 Background	1-3
	1.2 Objectives	
2.0	Computer Simulation Model	2-1
	2.1 Description of Original Model	2-1
	2.2 Modifications to the Model	2-15
	2.3 Limitations to Model	2-25
3.0	Computer Simulation Results	3-1
	3.1 Preliminary Considerations	3-1
	3.2 Study Approach	3-3
	3.3 Vehicle No. 39551	3-4
	3.4 Vehicle No. 38444	3-9
	3.5 Vehicle No. 39803	3-14
	3.6 Vehicle No. 39837	3-17
4.0	Analysis of Simulation Results	4-1
	4.1 General	4-1
	4.2 Simplified Analysis of Track Input	4-1
	4.3 Model Validation	4-4
5.0	Conclusions and Recommendations	5-1
	5.1 Conclusions	5-1
	5.2 Recommendations	5-3
6.0	References	6-1
Appendix A	- Ammended AAR Specifications D-65 - Testing Special Devices to Control Stability of Freight Cars	A-1
Appendix B	- Final Program Listing	B-1
Appendix C	- Program Flow Chart	C-1
Appendix D	- Computer Simulation Inputs	D-1
Appendix E	- Error Analysis	E-1

LIST OF ILLUSTRATIONS

Figure No.	Title	Page
2-1	AAR Freight Car Model	2-2
2-2	Inertial Reference Coordinates and Degrees of Freedom of Freight Car Model	2-5
2-3	Euler Angle Transformation	2-6
2-4	Rectified Sine Wave Simulation of Half-Staggered Rails	2-12
2-5	Sine Wave Simulation of Half-Staggered Rails	2-17
2-6	Snubber Friction	2-20
2-7	Hydraulic Damper Characteristics	2-22
2-8	Spring/Hydraulic Damper Suspension Configuration	2-23
2-9	Sample Analog Printouts	2-26
3-1	Vehicle No. 39551	3-5
3-2	ASF Ride Control Truck	3-6
3-3	Roll Response - Vehicle No. 39551	3-8
3-4	Vehicle No. 38444	3-10
3-5	Buckeye Six-Wheel and Eight-Wheel Trucks	3-11
3-6	Roll Response - Vehicle No. 38444	3-13
3-7	Roll Response - Vehicle No. 39803	3-16
3-8	Vehicle No. 39837	3-18
3-9	Roll Response - Vehicle No. 39837	3-20
4-1	Track Input Roll Angle Produced by Half-Staggered Rails	4-2
4-2	Normalized Roll and Torsional Inputs to Freight Car as a Function of Truck Center Spacing	4-6

EXECUTIVE SUMMARY

In order to enhance the safety and operational capabilities of a special class of freight cars owned by the Department of Defense, a series of roll stability tests were conducted by the DOT/FRA. These vehicles, designated DODX railcars, have a 100 to 200 ton capacity and are characterized by a relatively high center of gravity when carrying maximum load. In all a total of twelve cars were tested under various load and suspension configurations requiring approximately 60 complete test series. The originally planned test matrix called for considerably more configurations to be tested; however, time and funding would not allow this. For this reason recourse was made to computer simulation. This report describes the existing mathematical model which was used to simulate the roll stability of DODX cars.

The model, obtained from the AAR, is a 22 degree-of-freedon, non-linear, time domain model of railcars equipped with two-axle trucks. Certain modifications to this model were necessary to model the DODX railcars. These included the modification of the Coulomb friction damping, the addition of hydraulic dampers, and a track input or forcing function to simulate perturbed track as specified in the AAR Specification D-65. Substituting a second-order Runge-Kutta method for a fourth-order method allowed the increase in the integration step size and the practical implementation on a minicomputer. Finally, the output format was modified to show carbody roll angle and wheel lift in analog form.

Once the model was operational on the minicomputer, the standard methodology for computer simulation was used. First, all vehicles and load components were characterized using the best

available data and certain engineering approximations. Next, the model, configured identically to an actual field test, was run and compared to the field test results for the purpose of validation. In the event that reasonable agreement between model and field test was obtained, the model was adjudged valid and then used to obtain roll stability data on configurations other than that used for validation. That is, the numerical values of parameters used to characterize the vehicle and its load were changed in the model and a computer simulation was run for a vehicle which was not subjected to a full scale test. The results thus obtained provide the necessary data without the expense of the test.

The present study has shown that the modified mathematical railcar model can adequately model the response of DODX railcars to rock and roll track; i.e. repeated low joints. Although the model was designed for two-axle trucks, reasonable agreement with field tests was obtained for vehicles equipped with four-axle, span bolster trucks. In its present state the model does not appear to work well for articulated trucks with three-axles nor for long or torsionally flexible freight cars.

Results of the computer simulation of the two vehicles equipped with four-axle, span bolster trucks indicate that these vehicles operate within AAR specification. In fact, indications were found suggesting that some improvement in stability was achieved when the vehicle suspension spring rate was reduced or similarly when the load was increased. The vehicle equipped with the more conventional two-axle truck exhibited the best agreement between field test and computer validation when a dead band was added to the hydraulic stabilizer in the computer model. Further, it was concluded that, even though this particular vehicle does not presently conform to AAR roll stability specification, the addition of a hydraulic stabilizer operating over the full stroke would significantly improve vehicle performance.

The vehicle equipped with the three-axle trucks showed very poor agreement between field test and the validation run using the computer model. It should be kept in mind, however, that no attempt was made to vary parameters for the purpose of acquiring agreement between the field tests and computer model. Since no physical explanation for the discrepancy was found, it was assumed that either 1) some parametric quantity was incorrectly modeled or reported or 2) that the three-axle truck may have behaved differently compared to the two-axle trucks.

1.0 INTRODUCTION

1.1 BACKGROUND

Early in 1971, the Military Traffic Management Command (MTMC) iniated efforts to determine the roll stability, wheel lift and derailment tendency of certain DODX cars, characterized as 100-ton freight cars loaded with high-center-of-gravity containers. This effort was undertaken because railroads had been experiencing roll-stability-related difficulties with this configuration for several years. MTMC decided to evaluate the stability of these configurations and to make modifications as required to ensure acceptability for interchange service.

In April of 1971, stability tests were performed on the C&O/B&O Railroad. Suspension modifications, which included softer springs and hydraulic stabilizers, reduced car response to an acceptable level. The success of these tests prompted MTMC to test other cars of marginal stability. In September of 1972, the testing of five additional freight cars was authorized. This testing, again performed on the C&O/B&O Railroad, proved helpful in determining which cars required modification and to what extent.

By early 1974, MTMC decided that 12 additional car types (including three new procurements) should be tested. The variety of loads to be carried on these cars implied that some 60 configurations would need to be evaluated. Because of the scope of this program, the Federal Railroad Administration (FRA) was requested to conduct the tests; it was decided to utilize the recently constructed Train Dynamics Track at the Transportation Test Center in Pueblo, Colorado. ENSCO, under contract to FRA, designed and installed the actual instrumentation, collected the necessary data and performed the required data reduction for these tests.

During the course of the tests, it became apparent that an easier, less expensive method for determining the roll stability of freight cars was badly needed. In late 1974, ENSCO searched the literature covering existing computer models for simulating rail vehicle responses. The search indicated that most of the existing computer simulation models did not have the flexibility to handle the DODX application. However, one model developed by AAR appeared to be applicable with minor modifications. This model was described in a paper "Method of Analysis for the Dynamic Behavior of a Flexible Body Railroad Freight Car" by Yan Hai Tse (2).

ENSCO converted the model description and the computer program for use on the in-house RDS-500 minicomputer system. Initial attempts to make the computer model operational were only partially successful and computer simulation work was discontinued in February 1975 because of funding problems. Testing, however, continued at TTC on the cars previously selected. By July 1975, 10 of the 12 cars had been tested in a total of 45 different configurations.

FRA, MTMC and ENSCO continued to recognize the need to develop an effective computer simulation model for evaluating the roll stability of DODX cars as a practical alternative to expensive full-scale testing. In August 1975, ENSCO submitted a plan to FRA to accomplish this goal based on using the previously mentioned AAR model. This plan proposed the simulation of five DODX cars in a total of eight configurations. However, only four of these cars had been field tested and therefore only these four are reported herein. The field tests were to be used for validating the computer model. In October 1975, FRA approved the plan and ENSCO inplemented the DODX computer simulation effort described in this report.

1.2 OBJECTIVES

The objectives of the DODX Computer Simulation task were:

- To convert the AAR computer model for use on the RDS-500 minicomputer system.
- To modify the input forcing function so as to simulate the perturbed track specified in Amended AAR Specification D-65, "Testing Special Devices to Control Stability of Freight Cars" (included as Appendix A).
- To obtain the railcar parameters needed in the model for the four selected cars.
- To use results obtained in the full-scale tests of the four cars to validate the computer model.
- To compute vehicle responses for the four selected cars in the selected configurations.
- To prepare a final report summarizing and evaluating the computer simulation effort.

2.0 COMPUTER SIMULATION MODEL

2.1 DESCRIPTION OF ORIGINAL MODEL

2.1.1 Model Characteristics

The AAR model developed by U. H. Tse, under the guidance of G. C. Martin, served as the basis for ENSCO's simulation work on DODX railcar stability. A detailed description of this model is given in Reference 2. A general description is provided in this section and is based on material obtained from References 1 and 2.

In the AAR model (Figure 2-1), the carbody and its contents are modeled as two rigid half-bodies connected by a group of springs that simulate the torsional stiffness of the car and the bending stiffness about the lateral and vertical axes. This representation accounts for the major effects of carbody flexibility without the complexity of a model simulating a continuously flexible carbody.

Each half-body, integrated with its lading, rests on a bolster centerplate. This is modeled as a two-point contact with each point having a (very stiff) spring-like stiffness. When contact is lost at either point, the associated spring force is zero. When a certain amount of body roll occurs, contact will be made with one of the side bearings on the bolster. Each side bearing is modeled as a spring-damper (viscous) with a dead-zone (clearance) between it and the half-body.

This overall representation of the body/bolster interface permits realistic simulation in all of the possible operating modes. Thus at equilibrium and in moderate dynamic situations, the body makes contact with both contact points on the center-plate. With increased roll activity, the body can lose contact with one or the other of the centerplate pivot points. With a further increase in dynamic activity, the body will make

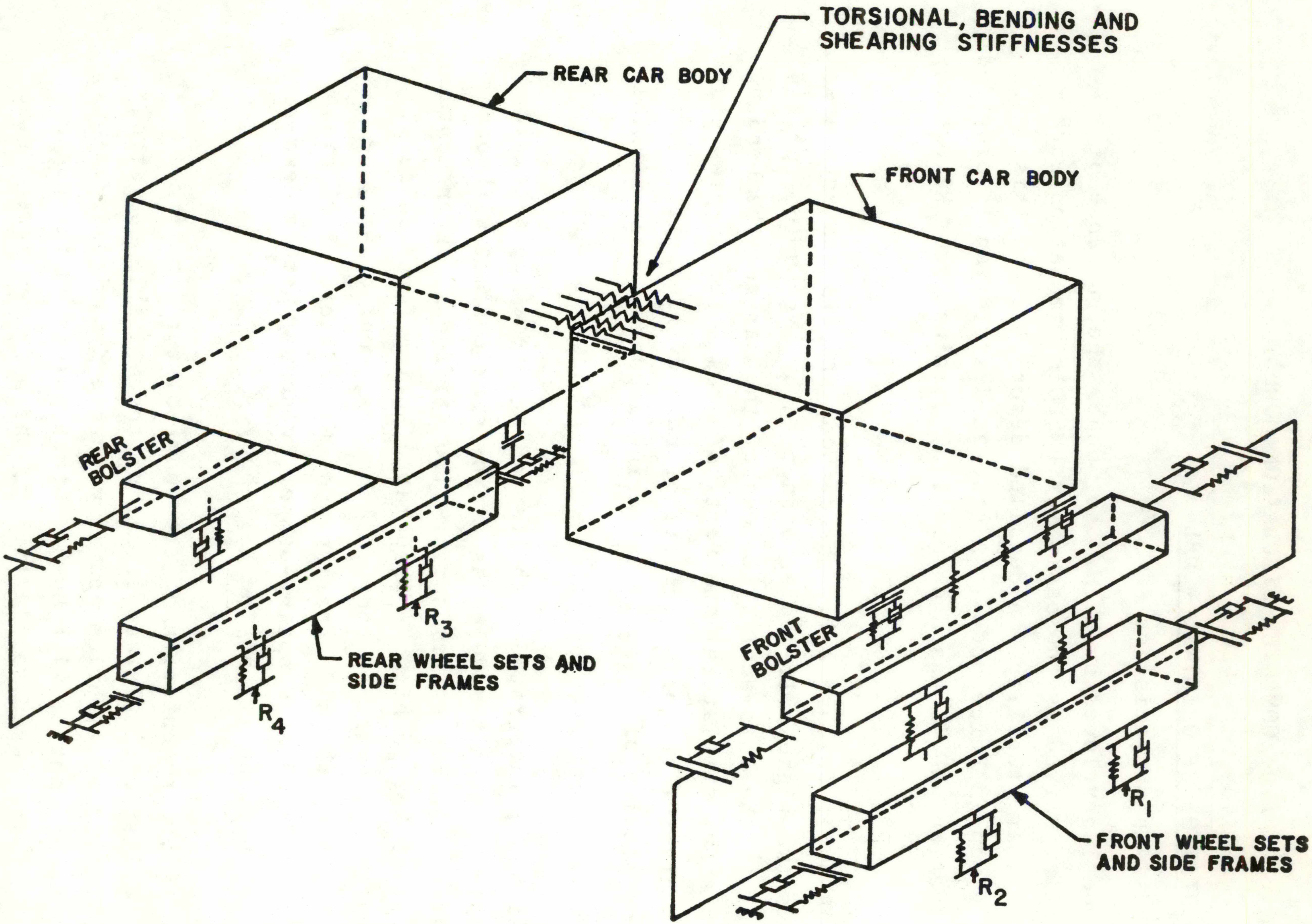


Figure 2-1. AAR Freight Car Model

contact with the appropriate side bearing. Finally, under some critical conditions the body may pivot about the side bearing and completely lose contact with the centerplate. At this point, wheel lift and suspension spring bottoming are likely to occur.

The bolster is supported on the side frame by two suspension groups, one on each side. Each suspension group is modeled by a single equivalent spring and a coulomb damper acting vertically and another spring and damper acting laterally. The vertical and lateral spring constants represent the corresponding stiffnesses of the suspension spring group. Similarly,the vertical and lateral coulomb dampers represent the corresponding characteristics of the snubber acting against the side frame column.

When the lateral motion of the bolster relative to the side frames is sufficient to cause gib contact, additional forces come into play. The additional lateral force is modeled by a (stiff) spring acting in parallel with the lateral spring constant of the suspension group. The additional vertical coulomb damping is modeled as a constant (coefficient of friction) times the lateral load on the gib.

To simplify the model, the side frames and wheelsets of each truck are represented as a single mass. This eliminates modeling of the truck pitching mode which was considered insignificant. Truck yaw is also considered insignificant for the purposes of this model. The vertical track input to the lumped mass is represented as a single mass. The vertical track input to the lumped mass representing both side frames and wheelsets occurs through the resilience of the track structure which is modeled as a spring-damper (viscous) at each end of this mass. Similarly, the lateral track input to the mass occurs through an equivalent spring-damper at each end and a dead zone (clearance) that represents the lateral gap between the rail and the wheelset.

Further assumptions of the model are that all displacements are small, all components move at the same velocity in the longitudinal direction, speed is constant in each run, and that each half-body and its respective bolster are laterally constrained to one another.

2.1.2 Development of the Equations of Motion

The motion of the freight car can be described relative to a set of inertial axes defined in Figure 2-2. A parallel set of inertial axes is assumed to exist at the center-of-gravity (at equilibrium position) of each car half-body, bolster and wheelset/side frame unit. A set of body fixed axes is located at the center-of-gravity of each unit. Initially (at equilibrium), each set of body-fixed axes coincides with the associated set of inertial coordinate axes. Hence, the motion of each unit can be described in terms of the translation and rotation of the body axes relative to the inertial axes.

The model assumptions reduce the degrees of freedom associated with each unit. Thus the assumption that all components move at a constant speed in the longitudinal direction eliminates consideration of longitudinal (Y) motion for each unit. Truck pitching and yawing are considered insignificant for the purposes of the model; thus bolster and wheelset/side frame angular motions are limited to roll about the longitudinal axis. The degrees of freedom for the model are summarized in Figure 2-2. Although these total 22, there are actually only 20 degrees of freedom since lateral motion of each car half-body and bolster (at the centerplate connection) are assumed to be the same.

The rotation of each car half-body with respect to its associated inertial axes is described by a set of Eulerian angles defined in Figure 2-3. The first is a rotation ψ about the X axis to form the i', j', k' axes. The next is a rotation θ about the j' axis to form the i", j", k" axes. Finally, a

DEGREES OF FREEDOM

CAR HALF-BODIES

FRONT T_x, T_z, R_x, R_y, R_z

REAR T_x, T_z, R_x, R_y, R_z

BOLSTERS

FRONT T_x, T_z, R_y

REAR T_x, T_z, R_y

WHEELS/SIDE FRAMES

FRONT T_x, T_z, R_y

REAR T_x, T_z, R_y

R - ROTATIONAL

T - TRANSLATIONAL

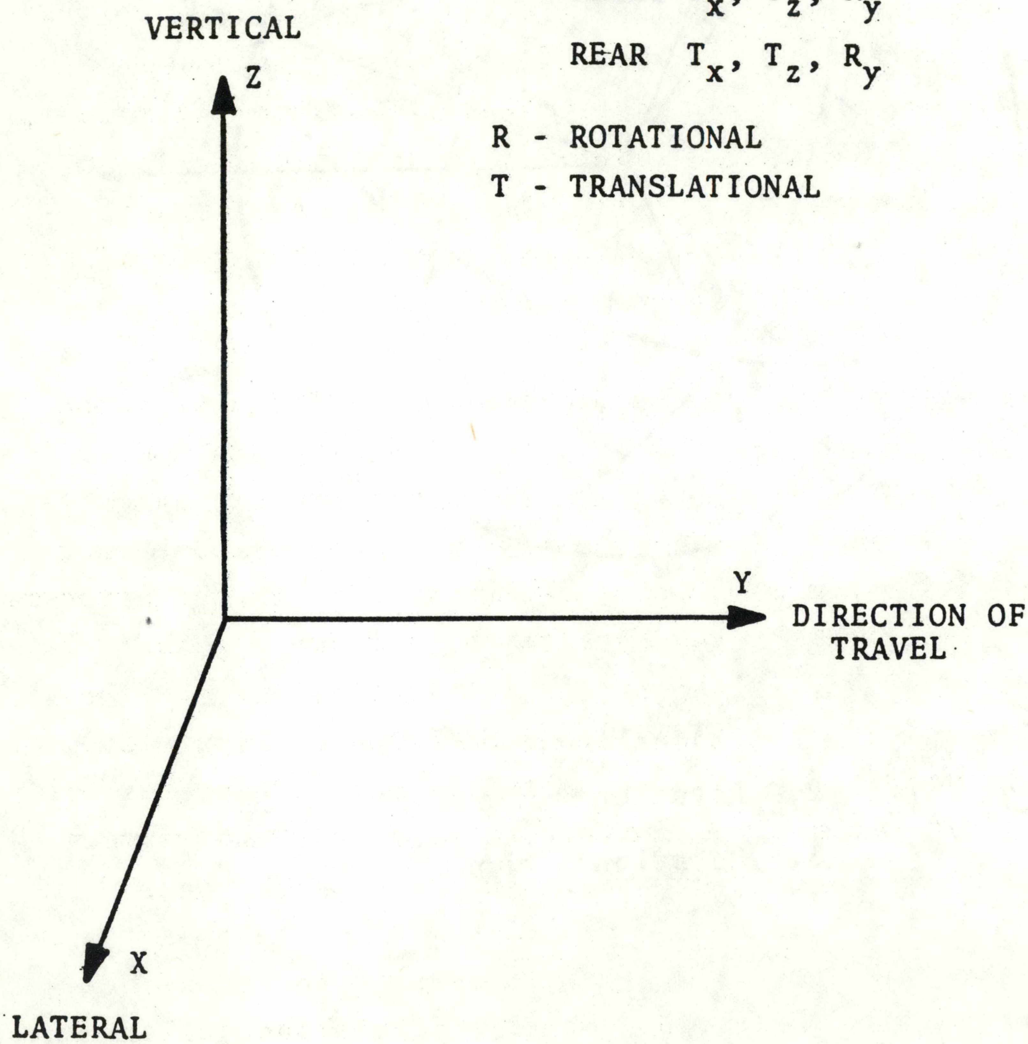
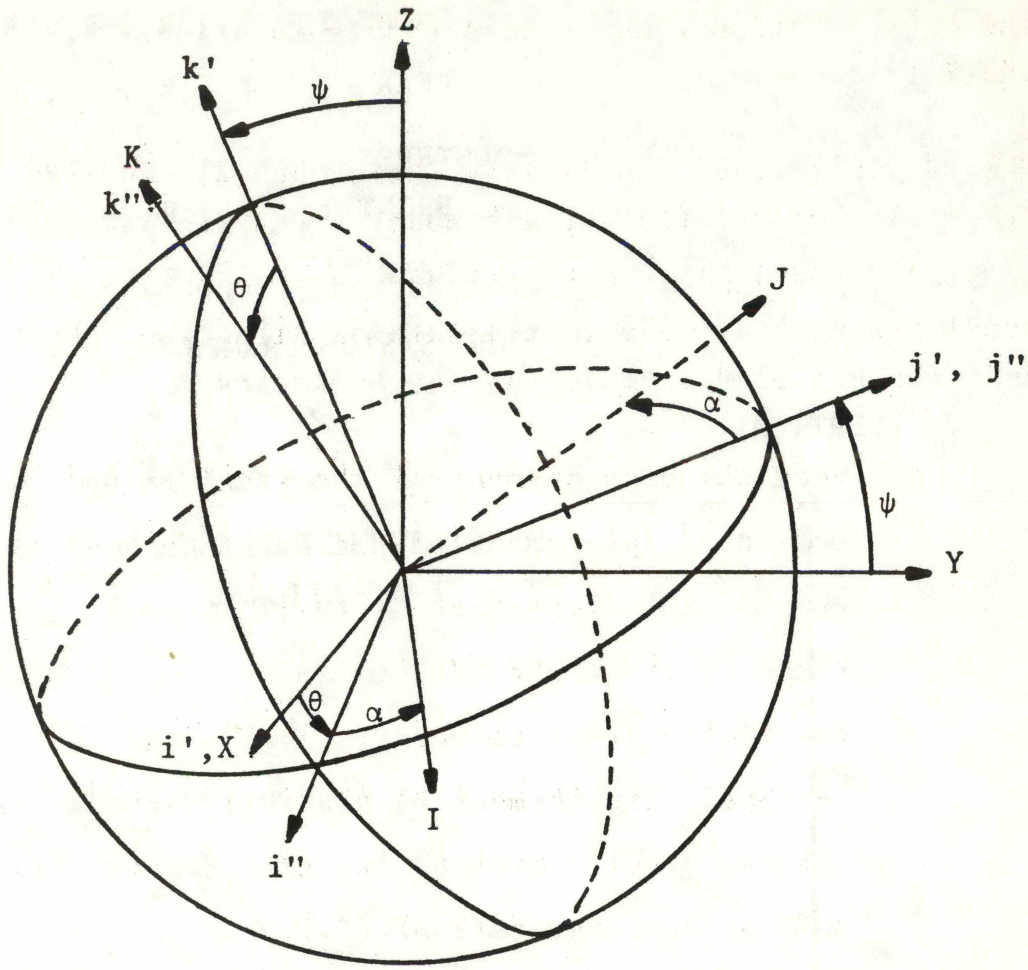


Figure 2-2. Inertial Reference Corrdinates and Degrees of Freedom of Freight Car Model



1. Rotation ψ about X axis.
2. Rotation θ about j' axis.
3. Rotation α about k" axis.

Figure 2-3. Euler Angle Transformation

rotation α about the k" axis forms the body-fixed axes I, J, K, axes. In the case of the bolsters and wheel set/frame units, the body rotation reduces to a single rotation θ (roll) about the Y axis.

The 22 generalized coordinates (Reference 2) required to describe the motion of the freight car model are as follows.

NOTE: X_1 and X_2 can be different and of opposite sign. The model has a shear mode in the lateral direction. However, this mode was not used in modeling the DODX cars.

Vertical displacement of the front carbody (z_1).

Lateral displacement of the front carbody (x_1).

Roll of the front carbody (θ_1).

Pitch of the front carbody (ψ_1).

Yaw of the front carbody (α_1).

Vertical displacement of the rear carbody (z_2).

Lateral displacement of the rear carbody (x_2).

Roll of the rear carbody (θ_2).

Pitch of the rear carbody (ψ_2).

Yaw of the rear carbody (α_2).

Vertical displacement of the front bolster (z_3).

Lateral displacement of the front bolster (x_3).

Roll of the front bolster (θ_3).

Vertical displacement of the rear bolster (x_4).

Lateral displacement of the rear bolster (x_4).

Roll of the rear bolster (θ_4).

Vertical displacement of the front wheelset (z_5).

Lateral displacement of the front wheelset (x_5).

Roll of the front wheelset (θ_5).

Vertical displacement of the rear wheelset (z_6).

Lateral displacement of the rear wheelset (x_6).

Roll of the rear wheelset (θ_6).

As previously noted, x_3 and x_4 are each constrained to be the same as the lateral centerpin motion of the respective car half-body. This reduces the number of independent coordinates, or degrees of freedom, to 20.

The equations of motion for the system are developed using Lagrange's equations (Reference 3). For a simple conservative system, these equations are

$$\frac{d}{dt}\left(\frac{\delta L}{\delta \dot{q}_j}\right) - \frac{\delta L}{\delta q_j} = 0 \qquad (1)$$

where

$L = T - V$ (Lagrangian)

T = Kinetic Energy

V = Potential Energy

q_j = Independent generalized coodinates

Since the freight car model is a non-conservative system, a modified form of Lagrange's equations is used namely;

$$\frac{d}{dt}\left(\frac{\delta L}{\delta \dot{q}_j}\right) - \frac{\delta L}{\delta q_j} = Q_j \tag{2}$$

where Q_j represent those generalized forces not arising from a conservative potential. Those forces that are derivable from a potential are still accounted for by the Lagrangian L.

Some non-conservative forces, such as viscous damping, can be derived from a velocity dependent functions F known as Rayleigh's dissipation function and defined by

$$F = \frac{dW_f}{dt} \tag{3}$$

where W_f = work done by the system against the viscous damping forces.

Then the generalized force component Q_j resulting from friction can be obtained from

$$Q_j = -\frac{\delta F}{\delta \dot{q}_j} \tag{4}$$

In this case, Lagranges equations can be expressed as

$$\frac{d}{dt}\left(\frac{\delta L}{\delta \dot{q}_j}\right) - \frac{\delta L}{\delta q_j} + \frac{\delta F}{\delta \dot{q}_j} = \overline{Q}_j \tag{5}$$

where $\overline{Q}_j$ is defined as those generalized forces not arising from either a conservative potential or a velocity-dependent potential such as the Rayleigh dissipation function F. In the freight car model, such remaining forces $\overline{Q}_j$ would be those associated with Coulomb friction.

Equations (5) are the ones used to develop the 20 second-order differential equations in the 20 independent generalized coordinates. In developing the expression for the kinetic energy of each mass, the assumption is made that the body-fixed axes are principal axes. Thus the kinetic energy of rotation of each mass can be expressed as

$$T_r = \frac{1}{2} I_x w_x^2 + \frac{1}{2} I_y w_y^2 + \frac{1}{2} I_z w_z^2 \qquad (6)$$

where I_x, I_y, I_z are the principal moments of inertia and w_x, w_y, w_z are the components of angular velocity in the body-fixed coordinate system.

With the previous assumptions on rotational freedom, only the two car half-bodies can have angular velocity components about all three axes. The other units are restricted to roll rotation (w_y) only. For the two car half-bodies, the angular velocity components can be expressed in terms of the Euler angles and their time derivatives utilizing straightforward coordinate transformation techniques. The result is

$$w_x = \cos \dot{\Psi} \cos \theta + \dot{\theta} \sin \alpha$$

$$w_y = \cos \dot{\theta} - \alpha \cos \dot{\Psi} \sin \alpha \qquad (7)$$

$$w_z = \dot{\Psi} \sin \theta + \dot{\alpha}$$

where $\dot{\Psi}$, $\dot{\theta}$ and $\dot{\alpha}$ represent the total derivative with respect to time. The kinetic energy of the entire system is then derived in terms of the generalized coordinates by adding the expressions for the translational and rotational energy of each mass. The potential energy associated with the various spring constants in the model are also derived in terms of the generalized coordinates. Lastly, the Rayleigh dissipation function for the system is obtained by summing terms of the form $\frac{1}{2} D_i V_i$ where D_i

are the various viscous damping coefficients and V_i are the associated damper velocities expressed in terms of the generalized coordinates and their time derivatives.

The potential energy associated with the weight of each mass is not used directly in equations (5) since the derived force is simply the weight of the mass acting in a vertical direction, and this weight can be incorporated as an external force on the right-hand side of the appropriate equation. Also incorporated separately in the equations of motion are the Coulomb friction forces Q_j since, as previously mentioned, these are not derivable from any generalized potential.

The resultant 20 second-order differential equations of motion are converted into 40 first-order differential equations via state variable techniques. These equations are then solved via the numerical method of Gaussian Elimination. Finally the equations are numerically intergrated utilizing a fourth-order, Runge-Kutta integration scheme. The track input function must now be specified in order to determine the wheelset inputs R_1, R_2, R_3, R_4, (see Figure 2-1). This is discussed in the following section.

2.1.3 Truck Input Function

The rock and roll problem of freight cars is essentially a resonance phenomenon that occurs when high center-of-gravity cars transverse track with half-staggered rails. Therefore the track input to the model is the geometry of half-staggered rails (Figure 2-4). The geometry of each rail is assumed to be that of a rectified sine wave as shown in Figure 2-4 and has the form:

$$\eta_{L,R} = A \left| \sin\left(\frac{\pi y}{L} - \phi_{L,R}\right) \right| \qquad (8)$$

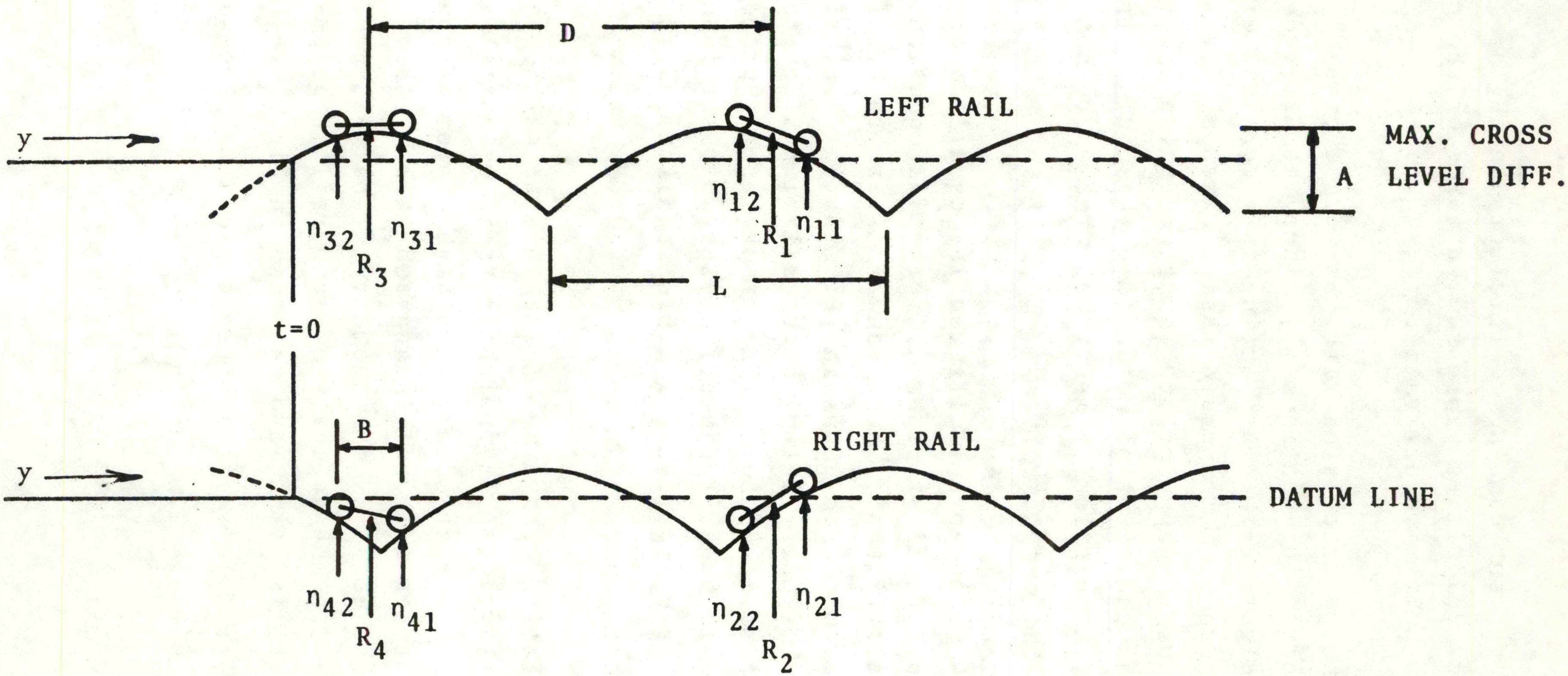


Figure 2-4. Rectified Sine Wave Simulation of Half-Staggered Rails

where

A = Profile amplitude variation from middle of rail section (high) to rail joint (low)

y = Distance along the rail

L = Length of rail section

$\phi_{L,R}$ = Phase angles of amplitude variation for left and right rails. (For half-staggered rails, $\phi_L - \phi_R = \frac{\pi}{2}$)

It is assumed that initially the car rests with all eight wheels on level track, and then encounters the half-staggered rail geometry as illustrated in Figure 2-4. For convenience the intersection of the level track (datum line) with the half-staggered rails occurs at a point (t = 0) where the crosslevel between the two rails is zero. Beginning at t = 0, the front wheels encounter the illustrated rail profile variations while the rear wheels are still on level track. At a time t = D/v, where D is the truck center spacing and v is the car velocity, the rear truck wheels encounter the half-staggered rails. From then on, both sets of wheels ride on the rectified sine wave rail profiles that represent the half-staggered rails.

The profile variation with time of each of the eight wheels will then be of the form:

$$\eta_{ij} = A \left| \sin (wt - \phi_{ij}) \right| \tag{9}$$

where $\omega = \frac{\pi v}{L}$

ϕ_{ij} = Profile variation phase angle of wheel ij, and ij is defined as shown in Figure 2-4.

Utilizing a geometric relationship (and letting $\phi_{11} = 0$), we obtain

$$\phi_{12} = \frac{\pi B}{L}$$

$$\phi_{21} = \frac{\pi}{2}$$

$$\phi_{22} = \frac{\pi}{2} + \frac{\pi B}{L}$$

$$\phi_{31} = \frac{\pi D}{L} \qquad (10)$$

$$\phi_{32} = \frac{\pi D}{L} + \frac{\pi B}{L}$$

$$\phi_{41} = \frac{\pi}{2} + \frac{\pi D}{L}$$

$$\phi_{42} = \frac{\pi}{2} + \frac{\pi D}{L} + \frac{\pi B}{L}$$

where D = truck center spacing and B = truck wheel base.

Since the two truck wheels on a side are treated as one in the model, the equivalent model input is simply the average of the two profile inputs. Thus

$$R_1 = \frac{1}{2} (\eta_{11} + \eta_{12})$$

$$R_2 = \frac{1}{2} (\eta_{21} + \eta_{22})$$

$$R_3 = \frac{1}{2} (\eta_{31} + \eta_{32}) \qquad (11)$$

$$R_4 = \frac{1}{2} (\eta_{41} + \eta_{42})$$

NOTE: Since the two truck wheels on one side are treated as one wheel, the accuracy of the model in predicting individual wheel lift is limited, i.e., the wheel lift due to pitch only could be predicted by the model at half amplitude.

Equations (9), (10) and (11) define the track input functions to the model.

2.2 MODIFICATIONS TO THE MODEL

The AAR freight car model described in Section 2.1 was converted for use on ENSCO's in-house RDS-500 minicomputer system with a resulting change of less than 2 percent. The conversion of this large scale model for use on a minicomputer was a significant accomplishment and produced considerable savings in cost. During the initial evaluation of this model, a number of modifications were made in order to make the model more effective in the prediction of the roll stability of DODX railcars. Some of these modifications were prompted by the need to reduce the long time required by the minicomputer to simulate a test run - approximately 1200 seconds for each second of real time. Modifications were also made to the track input function, the non-linear friction dampers and the output format. Another change involved the simulation of the Stucki hydraulic damping devices, which were not considered in the original AAR model. All of these modifications are described in the following sections.

2.2.1 TRACK INPUT FUNCTION

In validating the DODX computer model, the results of DODX roll stability tests on the TTC Train Dynamics Track were used. For those tests, the track had been artificially perturbed in accordance with the requirements of Amended AAR Specification D-65 "Testing Special Devices to Control Stability of Freight Cars". As a result of this perturbation, the rails assumed wave shapes that were approximately sinusoidal. Wiebe (Reference 4) also suggests near-sinusoidal rail profiles for rock and roll studies. Therefore, it was necessary to change the track input function for the model to two, out-of-phase sine waves representing the half-staggered rails, instead of the rectified sine wave discussed earlier.

Initially, the sine wave simulation for the half-staggered rails was simply

$$\eta_{L,R} = \pm A \sin \frac{2\pi y}{L} \qquad (12)$$

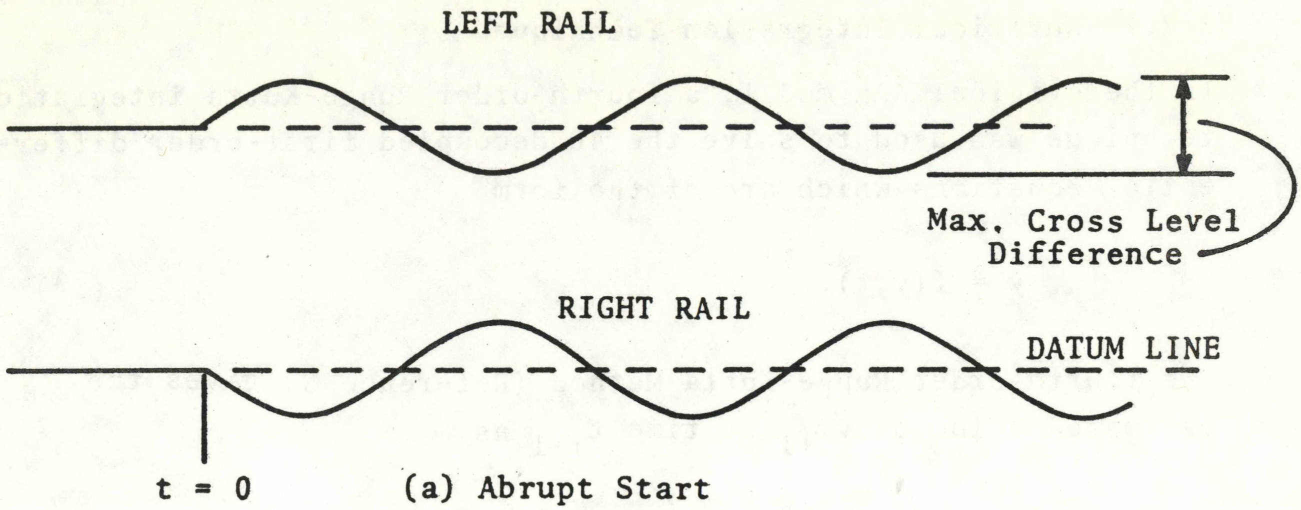
with the left and right rail profile variations of opposite sign. This is shown in Figure 2-5(a).

When this input function was used in the model, the initial response of the freight car was rather severe. The severe response required a small integration-step-size in order to follow the motion adequately. Since excessive computer run time was already a problem, it was decided to modify the track input function as follows:

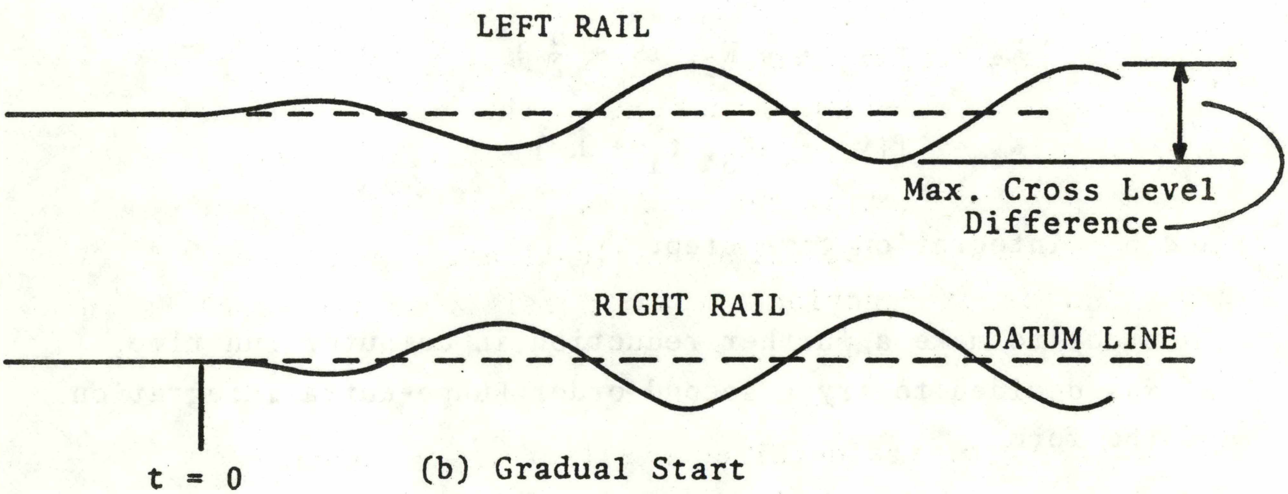
$$\eta_{L,R} = \begin{cases} \pm \frac{y}{L} A \sin \frac{2\pi y}{L} & ; \ 0 \leq y < L \\ \\ \pm A \sin \frac{2\pi y}{L} & ; \ L \leq y \end{cases} \qquad (13)$$

This representation for the half-staggered rails is shown in Figure 2-5 (b). The $\frac{y}{L}$ multiplier for the first cycle provides a gradual transition from the level track to the fully perturbed track. Using this input function to the model reduced the magnitude of the initial response of the freight car without significantly affecting the eventual peak values of the factors that measured roll stability (car roll angle and wheel lift). Using this input function, it was possible to increase the integration step size and reduce computer run time.

The formation of the detailed wheelset input functions R_1 through R_4 for the sine wave rails was a straightforward geometric task. It was similar to that outlined for the original AAR model. The time and distance phase relationships of the eight individual wheel profile input variations were first calculated. Then the construction of a single profile input representing the two wheels on each side was made by simple averaging.



(a) Abrupt Start



(b) Gradual Start

Figure 2-5. Sine Wave Simulation of Half-Staggered Rails

2.2.2 Numerical Integration Technique

In the original AAR model, a fourth-order Runge-Kutta integration technique was used to solve the 40 decoupled first-order differential equations which are of the form

$$\dot{y} = f(y,t). \tag{14}$$

The fourth-order Runge-Kutta Method (Reference 5) gives the estimated value of y_{i+1} at time t_{i+1} as

$$y_{i+1} = y_i + \frac{h}{6} (K_1 + 2K_2 + 2K_3 + K_4) \tag{15}$$

where

$$K_1 = f(y_i, t_i)$$

$$K_2 = f(y_i + \frac{h}{2} K_1, t_i + \frac{h}{2})$$

$$K_3 = f(y_i + \frac{h}{2} K_2, t_i + \frac{h}{2})$$

$$K_4 = f(y_i + hK_3, t_i + h)$$

and h = integration time step.

In order to make a further reduction in computer run time, it was decided to try a second-order Runge-Kutta integration of the form

$$y_{i+1} = y_i + \frac{h}{2} (C_1 + C_2) \tag{16}$$

where $C_1 = f(y_i, t_i)$

and $C_2 = f(y_i + hC_1, t_i + h)$

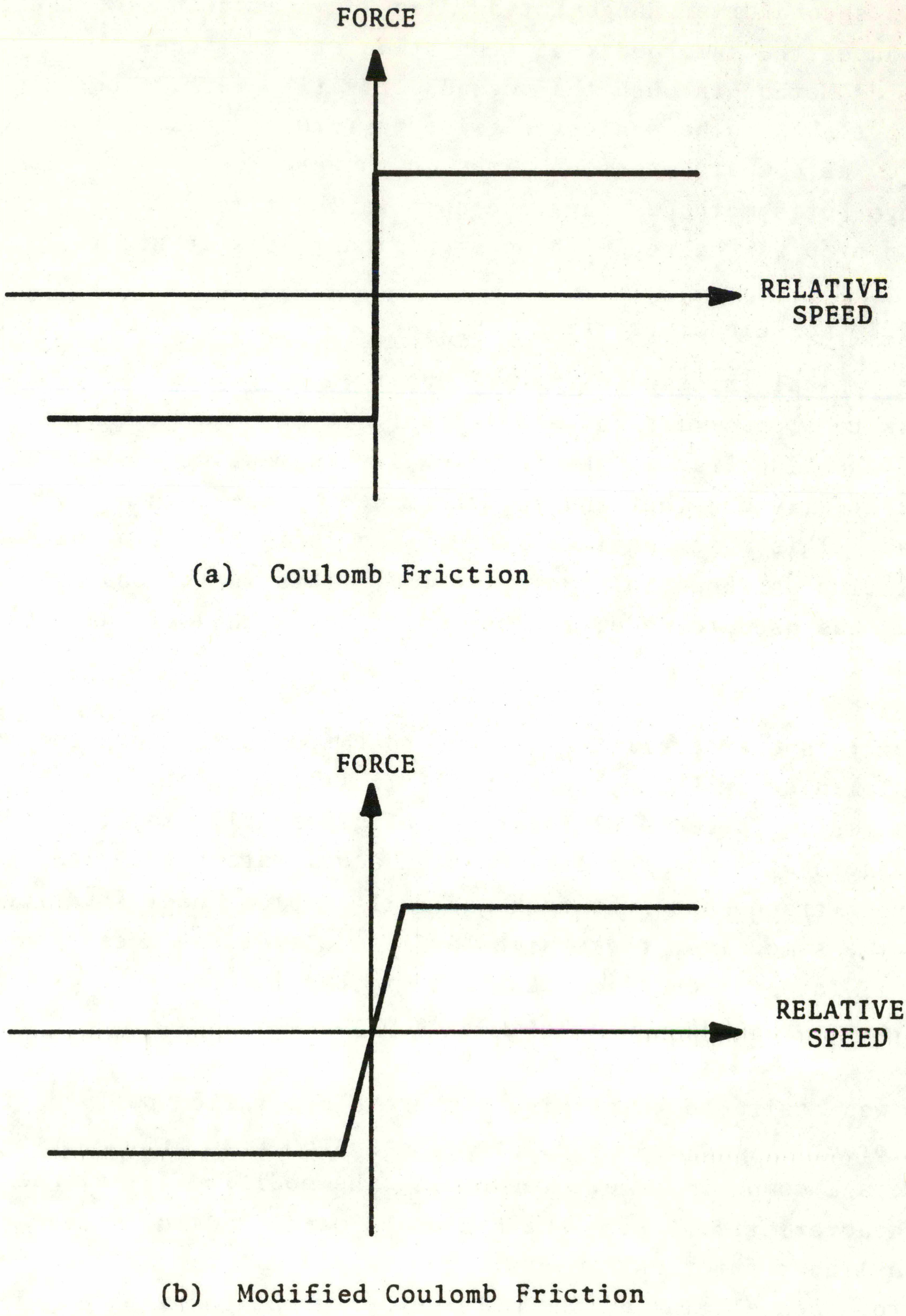
This second-order Runge-Kutta (also known as Heun's Method) produces the same order of truncation error as does the Taylor Series Method through the second derivative term. The function f(y, t) has to be evaluated twice to form the next estimated y_{i+1}, as compared to four times in the previous fourth order Runge-Kutta method. Thus the computation time for each integration step was halved with no significant loss in accuracy.

2.2.3 Non-Linear Friction Dampers

The typical friction damper (snubber),used on freight trucks, acts to oppose vertical and lateral motion between the bolster and the side frame. The frictional force during motion is essentially constant and is determined by the column spring load. This frictional characteristic is that of typical Coulomb friction as shown in Figure 2-6 (a). This is the characteristic that was used to model snubber friction in the original AAR model.

When this characteristic was incorporated in the computer model implemented by ENSCO, certain difficulties arose. Sudden large changes in force level (over an infinitesimally small speed change near zero) resulted in high acceleration transients that were extraneous to the rock and roll problem under investigation. At the same time, these high level accelerations necessitated a small integration time step to avoid the introduction of cumulative errors that could affect the major outputs.

It was desirable to eliminate these acceleration perturbations in order to increase the integration step size and thus reduce overall computer time. Therefore, the modified frictional characteristic of Figure 2-6(b) was introduced to represent the non-linear friction dampers. The very small linear zone near zero speed eliminated these large perturbations without affecting the overall results. The integration step size could then be increased. This combined with the improvement resulting from



(a) Coulomb Friction

(b) Modified Coulomb Friction

Figure 2-6. Snubber Friction

the use of the gradual transition factor for the track perturbation, provided an additional factor-of-two reduction in computer time.

2.2.4 Hydraulic Damper

There was no provision in the original AAR model for simulating the Stucki uni-directional hydraulic dampers. These dampers are commonly used in freight service, and are used on the four DODX cars that were to be used for model validation. Therefore it was necessary to add this capability to the model. The force vs. velocity characteristic of this hydraulic damper is shown in Figure 2-7.

Early validation runs using a lightly-loaded freight car revealed that the effective damping coefficient of this damper was much less than that listed by Stucki. In order to achieve a maximum carbody roll angle and wheel lift in the simulation that was comparable to that experienced in the field tests, it was necessary to use a simulated value of damping about one order of magnitude smaller than nominal. This was disturbing and led to an intensive examination of Stucki damper characteristics.

This examination showed that the construction of the Stucki damper was such that it might not provide damping over the full range of group spring travel, depending on the springs used. The damper is only effective over a range (Δ) from spring bottoming, as shown in Figure 2-8. Beyond this range, the damper provides zero force.

A lightly-loaded freight car would operate much of the time in the range of zero damping, i.e., near free-standing height of spring. Since the damping force acts only in compression, a force rectification is produced during any oscillation which causes a further upward shift in the average operating point.

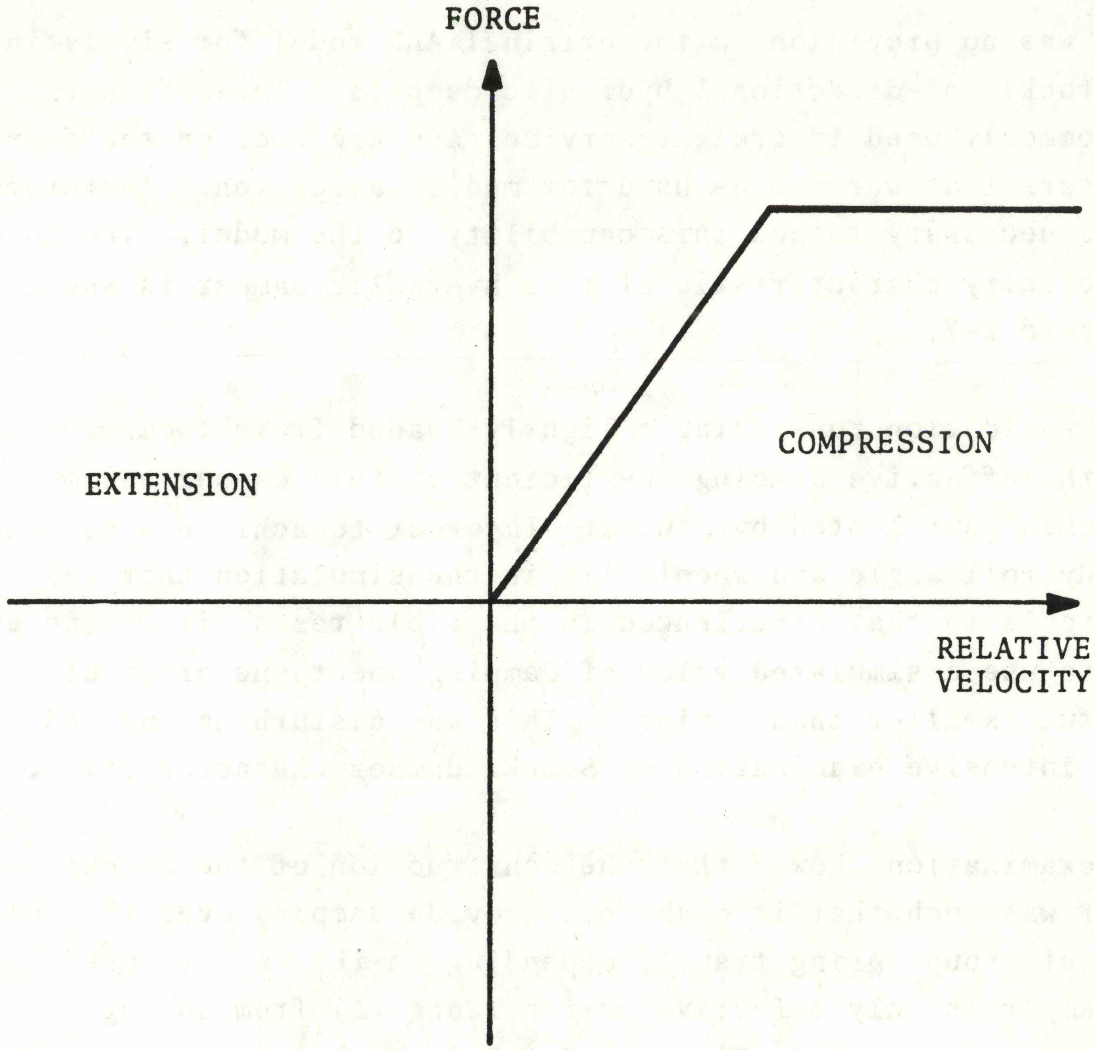


Figure 2-7. Hydraulic Damper Characteristics

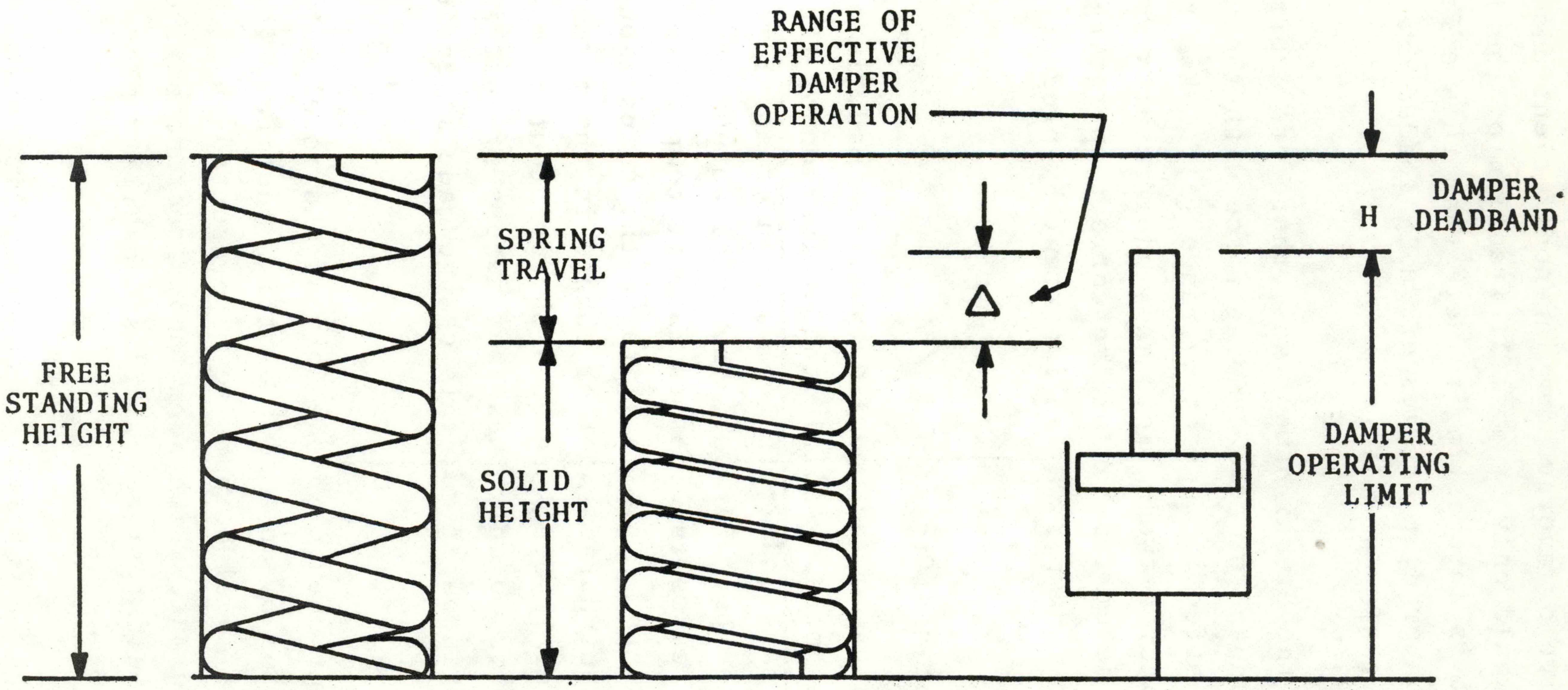


Figure 2-8. Spring/Hydraulic Damper Suspension Configuration

Hence, the effective or average damping coefficient under these conditions would only be a small fraction of the listed nominal value. It is interesting to note that this effect would not be encountered in studies of fully loaded freight cars, e.g., Wiebe (Reference 4).

The simulation of the Stucki damper was, therefore, corrected to include the deadband of zero damping force with the nominal value used in the effective operating range (Δ). When this was done, the discrepancy between field and model results was eliminated. This determination of the correct operating characteristics of the Stucki damper was an important by-product of the modeling task.

2.2.5 Model Output Modifications

Several modifications to the model output were made in order to make the results more useful in the evaluation of the roll stability of DODX cars and in the comparison of model results with field test results. For one, the model output format was changed in several cases in order to make it compatible with the field measurements. This facilitated the comparison of model and field test output data. Another change in the format of the output parameter listings reduced the printout from approximately 60 parameters to only those parameters of most interest. Besides reducing printout time, this change made it easier to interpret the results.

The most significant change in the form of the model outputs was the incorporation of an analog plotting routine. This routine enabled the model outputs to be presented in a continuous time history format, which permitted direct comparison of the outputs with field test data. This capability proved invaluable in the analysis of the results and the validation of the model. Samples of simulated data presented in this manner are shown in Figure 2-9.

2.3 LIMITATIONS OF MODEL

The modifications discussed in Section 2.2 resulted in a four-fold increase in computer efficiency. One second of real-time data required 300 seconds of minicomputer time instead of the 1200 seconds required previously. Even with the improvement, average run (12 seconds real-time) required one hour of mini-computer processing time. The computer usage costs were very low; however, the long run times were a handicap in model validation and in the parametric studies required to gain an understanding of the roll stability of DODX cars and the related parametric sensitivities.

The freight car model was designed to simulate two-axle freight trucks, which form the great majority of freight trucks in existence. However, many of the DODX configurations to be simulated contained three-axle or four-axle trucks. An accurate simulation of these car types would have required a substantial revision of the model to incorporate the additional degrees of freedom associated with these trucks. This was beyond the scope of the project.

In order to simulate a three-or four-axle truck with this model, a worst case approach was utilized in which the truck was treated as an equivalent two-axle truck of the same total mass and suspension characteristics. This was considered worst case because an actual three-or four-axle truck geometrically filters the track perturbations so as to transmit a track input of lower amplitude than a two-axle truck. At the same time, it was felt that the roll-resonant-frequency of a freight car would not be markedly affected since the total truck suspension characteristics would

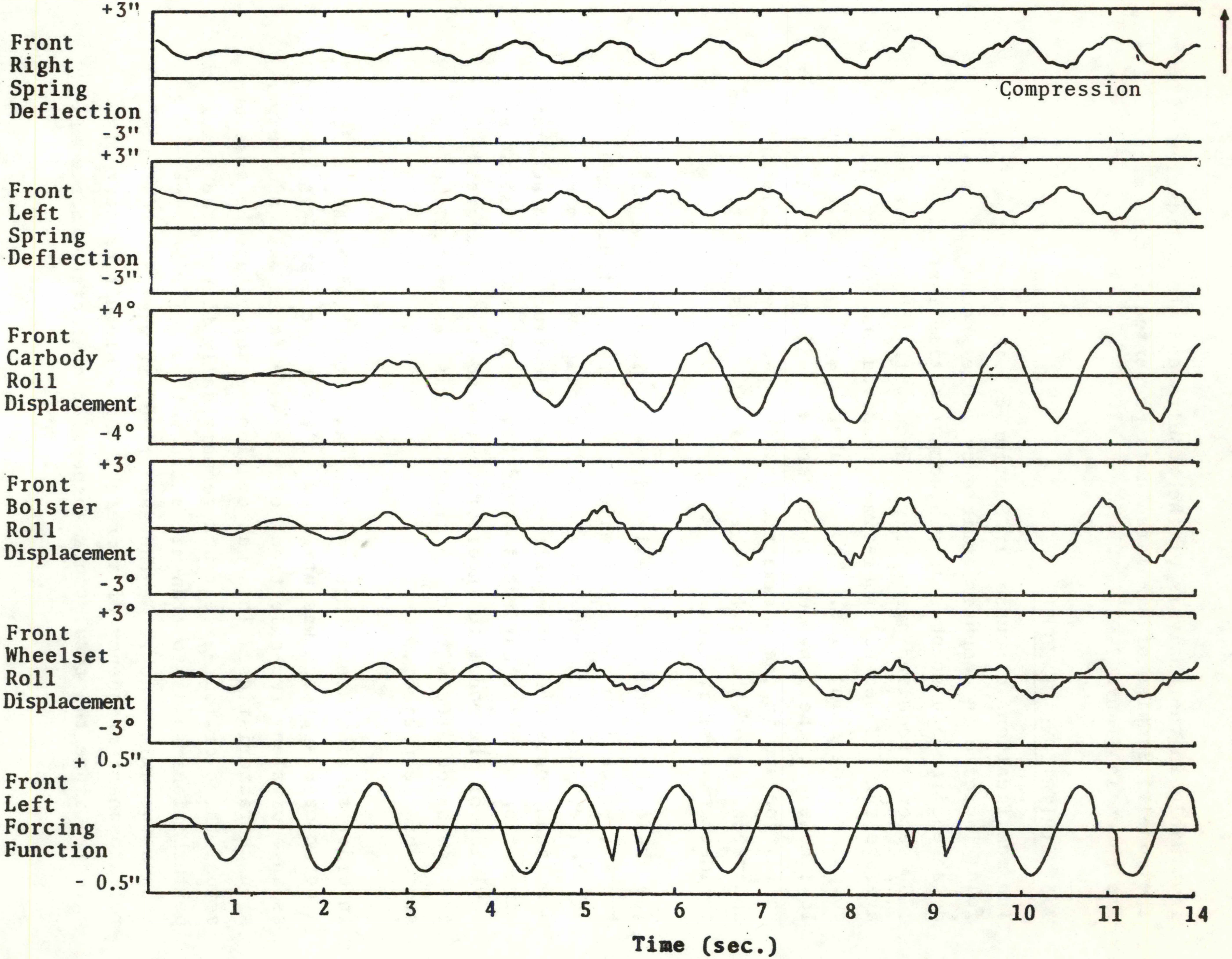


Figure 2-9. Sample Analgo Printouts

be essentially the same. However, wheel lift as determined in the model and as measured in the field could differ appreciably because of the much greater flexibility of the three-or four-axle truck.

The modeling of a flexible car as two rigid half-bodies connected by a group of torsional and bending springs is considered effective for investigation of roll stability as long as the maximum torsional and bending rotations remain small. This is probably not the case for some of the longer, more flexible freight cars. In these cases, single values of roll, pitch and yaw for each car half-body would not be representative of actual car body response. The validity of the computed roll responses in the simplified model would become questionable in the case of the more flexible freight cars. In addition, the comparison of computed and field measured values of roll response becomes a problem since car roll angle, as measured at the front bolster location, could differ appreicably from that experienced at the center-of-gravity of the front car half-body, when the car is experiencing appreciable torsion. The model of course can only yield a single value of roll for each rigid half-body, which may or may not be an accurate indication of actual roll at the half-body center-of-gravity. For these reasons, the simplified model is considered to be of decreasing value as the freight car torsion and bending flexibility becomes large.

3.0 COMPUTER SIMULATION RESULTS

3.1 PRELIMINARY CONSIDERATIONS

In order to validate and utilize the computer model described in Section 2.0 to study DODX railcar roll stability, it was necessary to perform several preliminary steps. These included:

- Determination of railcar dimensional and inertial parameters.
- Determination of truck suspension characteristics (lateral and vertical stiffness and damping coefficients).
- Determination of equivalent stiffnesses (and damping coefficients where applicable) for the centerplate, side bearings, side frames, and trucks.
- Determination of equivalent torsional bending and shearing stiffness between the front and rear half-bodies of the car.

The first item was a straightforward task involving the study of manufacturer's drawings and other references such as the car and locomotive cyclopedia, the solicitation of information directly from car truck manufacturers, the performance of field measurements, and finally calculation of parameters such as center-of-gravity and moments of inertia from a knowledge of component weight distributions and dimensions.

The determination of truck suspension stiffness and damping coefficients was also a straightforward task. The vertical stiffness characteristics were available from manufacturer's data. The lateral spring constant of each suspension was calculated based on theoretical considerations and a knowledge of the vertical characteristics. The vertical and lateral values of Coulomb friction provided by the snubber were also available from manufacturer's data. The vertical Coulomb friction associated with gib contact was modeled as a constant (coefficient of friction) times the lateral load on the gib. The only area that presented any difficulties was the damping characteristic of the hydraulic damper. As discussed in Section 2.2.4, it was discovered that the published characteristic applied only to a certain positional range. Outside of this range the damping force was zero. This operating characteristic was accommodated by incorporating the appropriate deadband in the damper model.

The third item involved the estimation of spring constants (and damping coefficients where applicable) for a number of components characterized by a high degree of stiffness. The steel-on-steel stiffnesses associated with centerplate contacts and side bearing contacts were evaluated from the modulus of elasticity for steel and the estimated contact areas. The side frame lateral stiffness was estimated based on practical deflection limits under peak loads. Track stiffness for the model was calculated using linear estimates of track stiffness (in lb/ft/ft) times the axle spacing distance. Values used by Martin & Tse (2) in his model for all of these stiffness parameters were used as starting points in the estimating process. Since rock and roll is a relatively low frequency phenomenon, the model outputs remained unaffected over a wide range of trail values for these stiffness coefficients. Thus considerable latitude existed in the final selection and this was utilized to minimize numerical integration problems.

The last item required the selection of various stiffness coefficients between the two car half-bodies, so that the model would approximate the effects of actual car flexibility. In the case of the shearing stiffnesses, the only practical requirement was that these be high enough to maintain negligible lateral motion between the two half-bodies. In tests of the model, it was found that these coefficients could be set at zero and still maintain the requirement of negligible lateral motion. Therefore, the shearing stiffness coefficients were set at zero to eliminate all force transients at the junction.

The torsional and bending stiffness coefficients were selected at levels that would produce expected natural frequencies of oscillation in each axis for the given car configuration. The value of torsional stiffness was particularly important since it could directly affect the primary model outputs (maximum car roll angle and wheel lift). Information from various sources including Reference 7 was utilized to obtain representative values for these flexural coefficients of each car configuration.

3.2 STUDY APPROACH

Computer model validation runs were performed for each of the four DODX railcar configurations that had been previously tested. The field test results for these configurations were available from the DODX Railcar Stability Tests previously performed by ENSCO (Reference 7). The primary stability outputs for each model validation run were directly compared with the respective field test results. No attempt was made to artifically adjust model parameters to achieve a best match of model outputs to field test results. Thus the degree of correlation achieved in each case provided a good indication of model validity and its usefulness as a tool for predicting railcar roll stability.

In two cases, involving DODX Vehicles No. 39551 and No. 39837, the correlation achieved between the validation runs and the field tests was excellent. The confidence that was established in the validity of the model and in the model parameter values for these vehicles encouraged additional computer studies of other vehicle configurations. The roll stability of these additional configurations could then be evaluated with a high degree of confidence. The results of these model validation and simulated configuration runs are presented in subsequent sections.

Comparison of field and model validation runs for the 39803 vehicle resulted in acceptable correlation. However, the degree of confidence is somewhat less than that for the two vehicles mentioned previously. Two additional configuration runs along with the validation result for this vehicle are presented. Validation runs involving the 38444 vehicle resulted in poor correlation with field results.

Time and funding limitations of the project prevented the intensive study required to pinpoint and correct the simulation problem areas causing the discrepancies. Since adequate model validation had not been achieved for the 38444 vehicle, it was considered ineffective to proceed with the simulations of additional configurations involving this vehicle. In a related case involving previously untested DODX Vehicle 39904, a 375,000 pound flatcar, the simulation of two proposed configurations was not performed since similar modeling uncertainties existed for this vehicle as for the 38444.

3.3 VEHICLE NO. 39551

3.3.1 Vehicle Description

This vehicle (Figure 3-1) is an 80-ton flatcar constructed of fabricated steel with a special container frame permanently attached to the flatcar frame. The car is 51 feet long, 10 feet wide, and has a light weight (unloaded) of 53,800 pounds. Two ASF Type A-3 ride control trucks (Figure 3-2) are used with a truck center spacing of 39 feet-8.5 inches. This is a two-axle, four wheel truck with an axle spacing of 68 inches. The truck utilizes 6.5-inch x 12-inch roller bearings and one Stucki HS-6 hydraulic damper in each spring group. The weights on wooden blocks shown in the picture are for the purpose of simulating the container load.

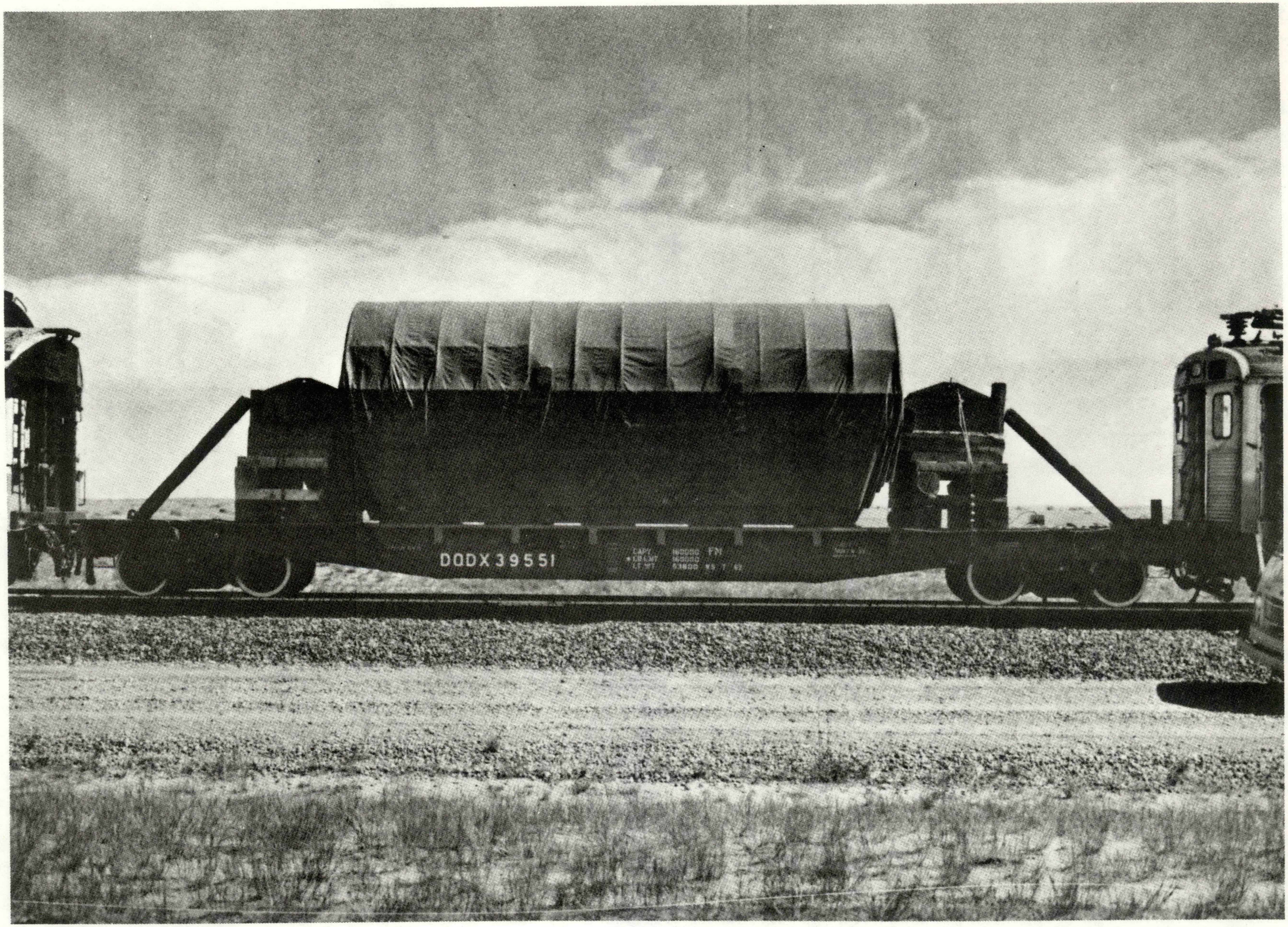


Figure 3-1. Vehicle No. 39551

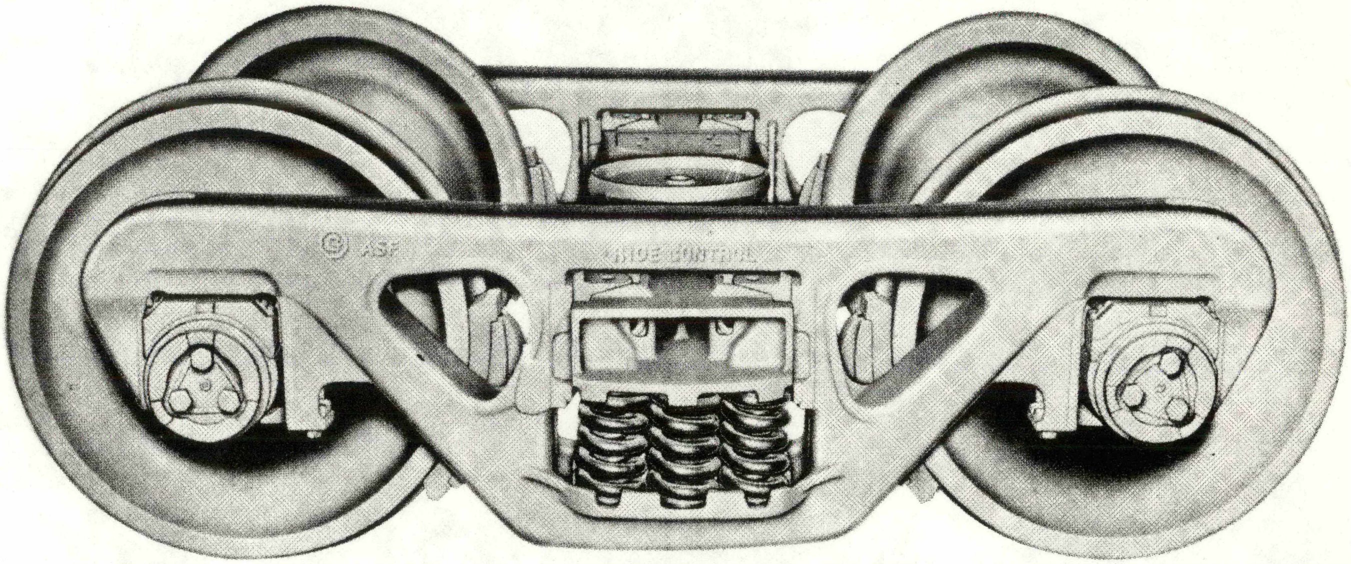


Figure 3-2. ASF Ride Control Truck

3.3.2 Field Test Results

This vehicle was tested on 18 December 1974 in an empty-with-container configuration. Each spring group of the ASF ride control trucks was equipped with six D-4 outer springs, four D-3 inner springs, and an HS-6 hydraulic stabilizer. The load (not including light weight) was 72,000 pounds at 56 inches above the car deck. The roll response of this configuration is given below:

Speed (mph)	Peak Roll Angle (Degrees Peak-to-Peak)	Wheel Lift (Inches)
5	1.6	0
10	1.6	0
12	2.1	0
14	2.1	0
16	2.6	0
18	3.2	0
20	3.6	0
22	4.2	1/4
23	6.0	1+
24	5.4	1+

3.3.3 Model Validation Results

The configuration described in paragraph 3.3.1 was simulated in the computer model. The roll response results are shown in Figure 3-3 together with those of the previous field tests. As can be seen from the curves, the model validation results agree very well with field results. The peak roll angle and peak wheel lift in each case are within 10 percent of each other. The close agreement of field and model validation results suggest that the computer simulation model could be used reliably for assessment of similar DODX railcar stability. Note that in both field test and model validation results, the roll response exceeds the maximum six degrees peak-to-peak allowed by the amended AAR specifications D-65 (Appendix A).

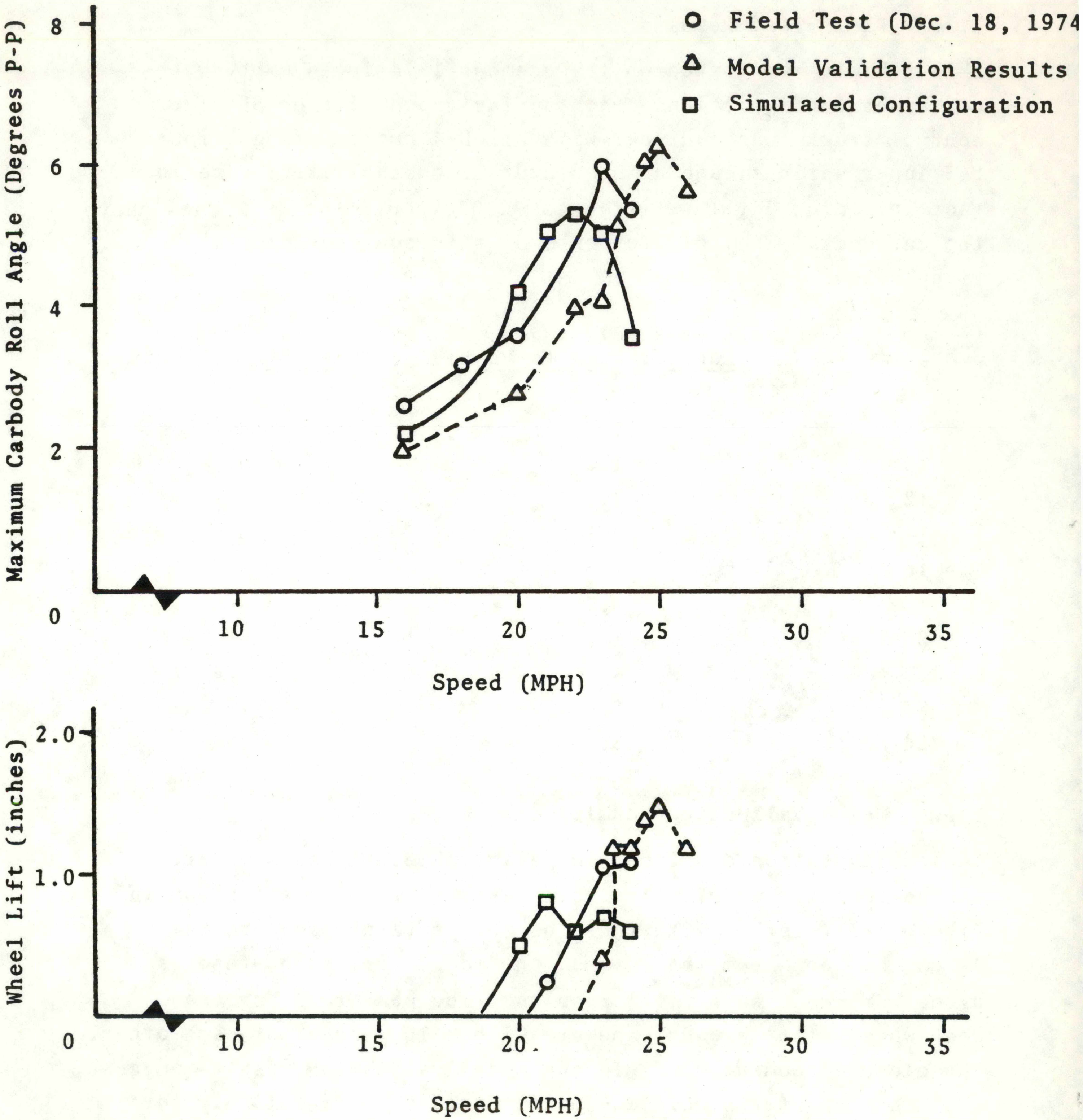


Figure 3-3. Roll Response Vehicle No. 39551

3.3.4 SIMULATED CONFIGURATION

In this configuration, one D-4 outer spring was removed from each spring group. The load was increased to 90,000 pounds and the center-of-gravity to 60 inches above the car deck. The roll response results for this simulation are shown in Figure 3-3 together with those of the previous field tests and the model validation runs. The roll response of this vehicle configuration indicates a reduction in maximum wheel lift and roll angle and a slight reduction in critical speed. The maximum wheel lift, however, is not in compliance with the amended AAR Specification.

3.4 VEHICLE NO. 38444

3.4.1 Vehicle Description

This vehicle (Figure 3-4) is a 100-ton flat car made of fabricated steel. It is 54 feet long by 10 feet wide, and has a light weight (unloaded) of 70,800 pounds. Two Buckeye six-wheel trucks are used at a truck center distance of 36 feet. Each truck is three-axle, six-wheel, and has an axle center distance of 54 inches. The truck utilizes 6-inch x 11-inch friction bearing journals, and one Cardwell friction damper and one Stucki HS-6B hydraulic damper per spring group. There are four spring groups per truck. The Buckeye six-wheel truck is shown in more detail in Figure 3-5.

3.4.2 Field Test Results

This vehicle was field tested on 23 June 1975 with a load of 82,868 pounds at 61.8 inches above the car deck. Each of the spring groups contained three D-3 outer springs, three D-3 inner springs, and an HS-6B hydraulic stabilizer. The peak roll response during these tests is given below:

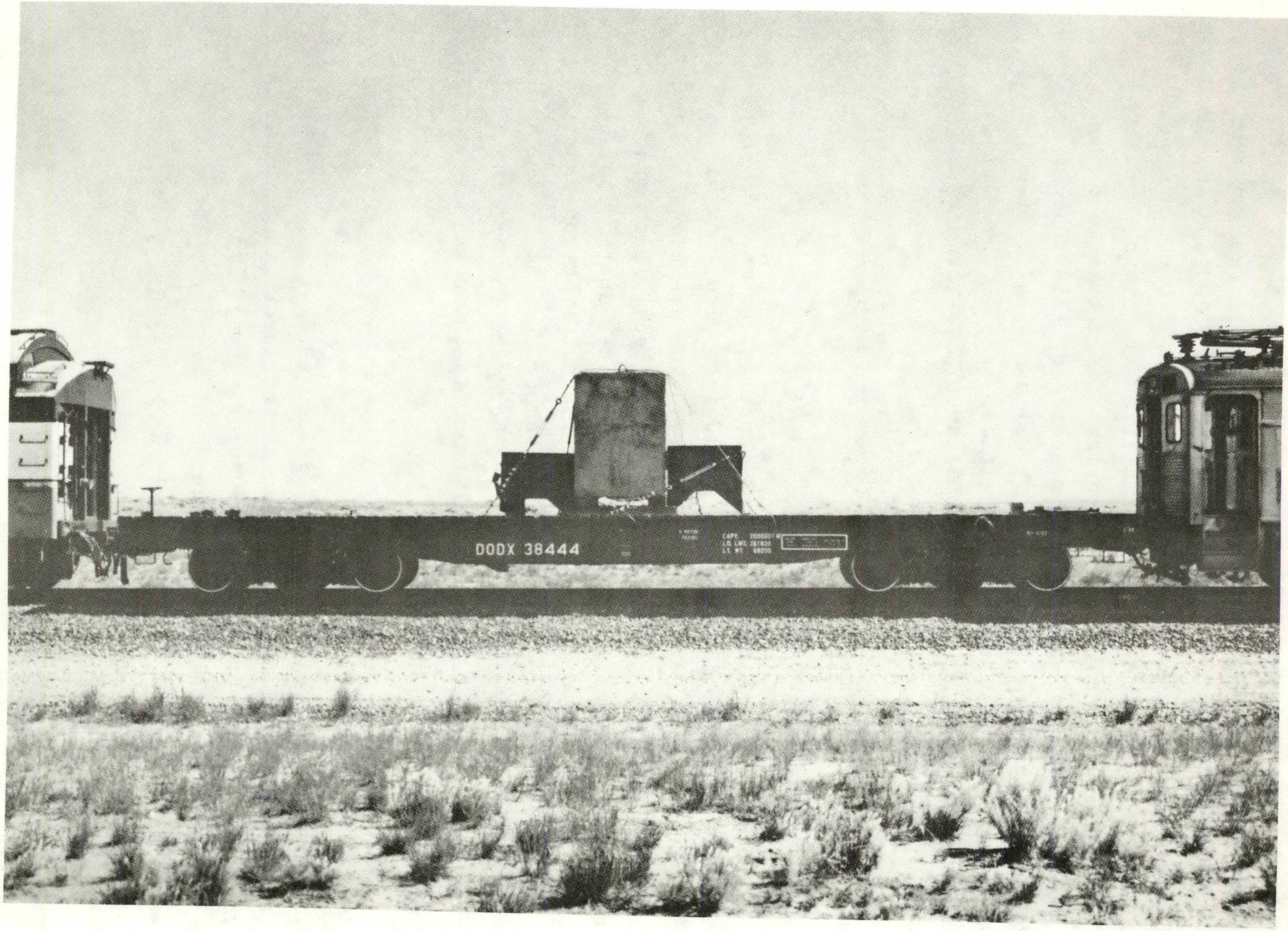


Figure 3-4. Vehicle No. 38444

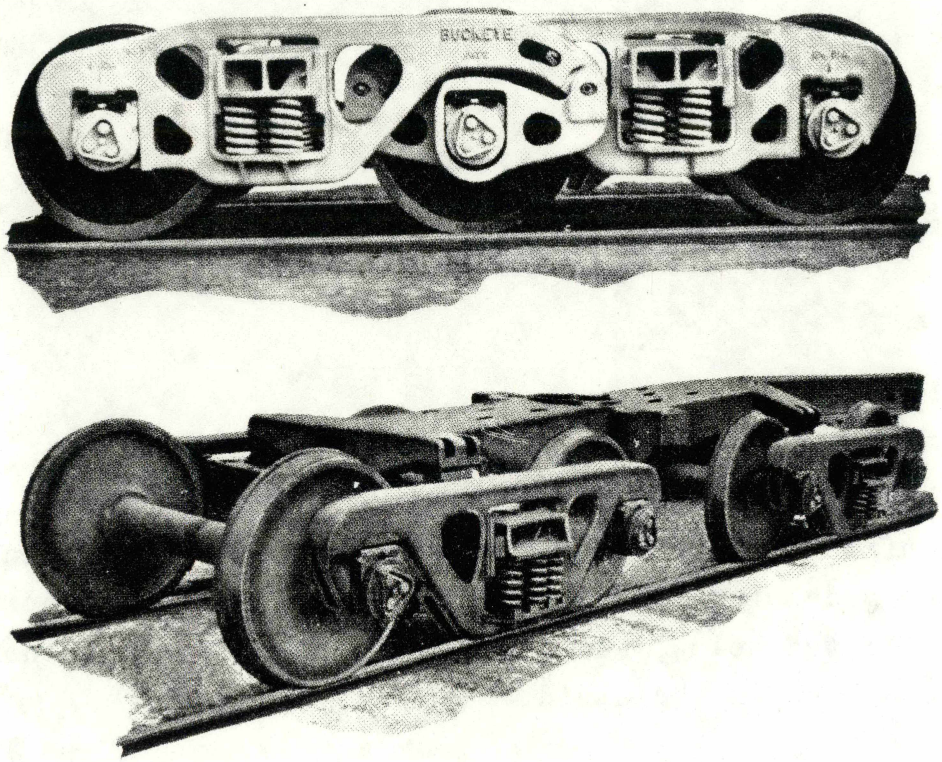


Figure 3-5. Buckeye Six-Wheel and Eight-Wheel Trucks

Speed (mph)	Peak Roll Angle (Degrees Peak-to-Peak)	Wheel Lift (Inches)
5	1.4	0
10	1.6	0
12	2.4	0
14	3.5	0
16	4.4	0
18	4.4	0
19	5.3	(minor)
20	4.8	(minor)
21	4.2	0
22	4.0	0
24	2.4	0
26	1.5	0
30	1.0	0
35	0.7	0

3.4.3 Model Validation Results

The same configuration tested in the field was simulated in the computer model for validation purposes. The resulting roll response is listed below, and plotted in Figure 3-6 together with that measured in the field:

Speed (mph)	Peak Roll Angle (Degrees Peak-to-Peak)	Wheel Lift (Inches)
19	2.1	.2
21	4.2	1.2
23	6.6	1.2
24	5.4	1.2
25	4.0	1.0

The agreement between the two roll angle plots is only fair. The peak roll angle in field tests was 5.3 degrees and occurred at 19 mph. In the model validation run, the peak roll angle was 6.6 degrees and occurred at 23 mph. The biggest discrepancy between field and model results was in the magnitudes of wheel

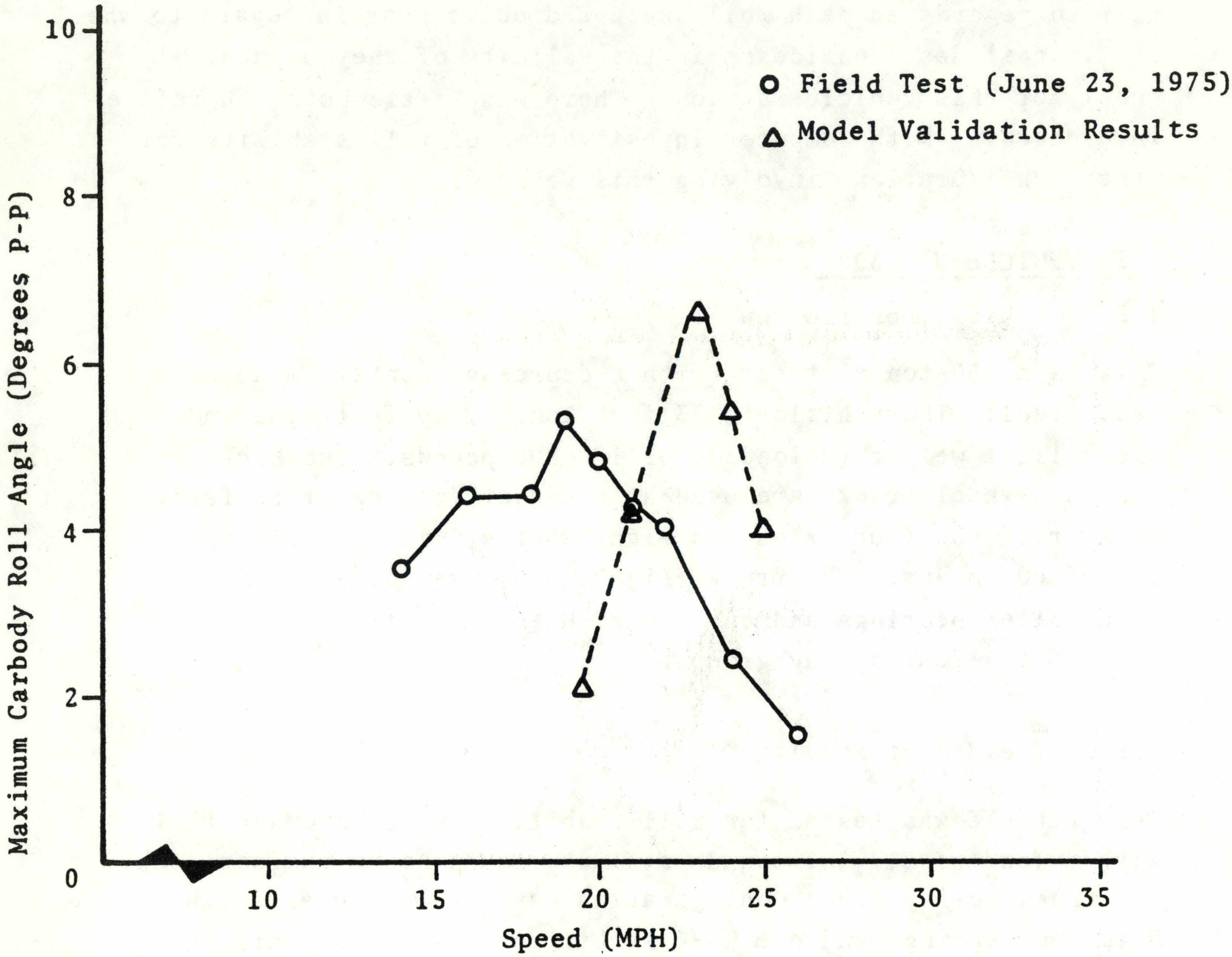


Figure 3-6. Roll Response - Vehicle No. 38444

lift. Although the field test results showed negligible wheel lift, the model indicated wheel lifts of 1.2 inches.

Since the correlation between field and model results was only fair in regards to peak roll angle and quite poor in regard to wheel lift magnitudes, confidence in the validity of the computer model for this vehicle was low. There was little point therefore in proceeding with computer investigation of roll stability for other configurations involving this vehicle.

3.5 VEHICLE NO. 39803

3.5.1 Vehicle Description

This is a 150-ton flat car (with a depressed center) made of cast steel. The vehicle is 73 feet long by 10 feet wide and has a light weight (unloaded) of 170,200 pounds. Two Buckeye double 4-wheel trucks are used at a center spacing of 53 feet. Each truck has four axles and eight wheels, with an axle spacing of 60 inches. The truck (Figure 3-5) uses 6.5-inch x 12-inch roller bearings and one Stucki HS-6 hydraulic damper for each of the four spring groups.

3.5.2 Field Test Results

This vehicle was tested for roll stability on 22 November 1974 with a load of 212,337 pounds at 79.8 inches above the car deck. The truck spring group configuration was six D-4 outer springs, six D-4 inner springs and one HS-6 stabilizer. The test data shows that this configuration was quite stable and easily met the roll stability criteria (Appendix A). The roll response during these tests are as follows:

Speed (mph)	Total Roll Angle (Degrees Peak-to-Peak)	Wheel Lift (Inches)
5	0.6	0
10	0.8	0
12	0.9	0
14	1.2	0
16	1.3	0
18	1.3	0
20	1.7	0
22	1.6	0
24	1.8	0
26	2.0	0
28	1.8	0
30	1.6	0
32.5	1.2	0

3.5.3 MODEL VALIDATION RESULTS

The previous field-tested configuration for Vehicle No. 39803 was simulated in the computer model for validation purposes. The roll angle results for this model validation run are plotted in Figure 3-7 together with those of the previous field tests and additional simulated configuration results. The model and validation results differ by 51 percent in critical speed and 20 percent in maximum roll angle. The discrepancy in maximum roll angle is in part attributable to the worst-case simulation of the four-axle truck as discussed in paragraph 2.3. No wheel lift was experienced in the model validation results. The minimum at 20 mph in the model roll response may be due to the interaction of the vehicle torsional response with the basic roll response. This is discussed more in Section 4.0. Based on the results shown in Figure 3-7, it was assumed that the model could be used to predict the roll stability of additional configurations involving this vehicle with acceptable accuracy.

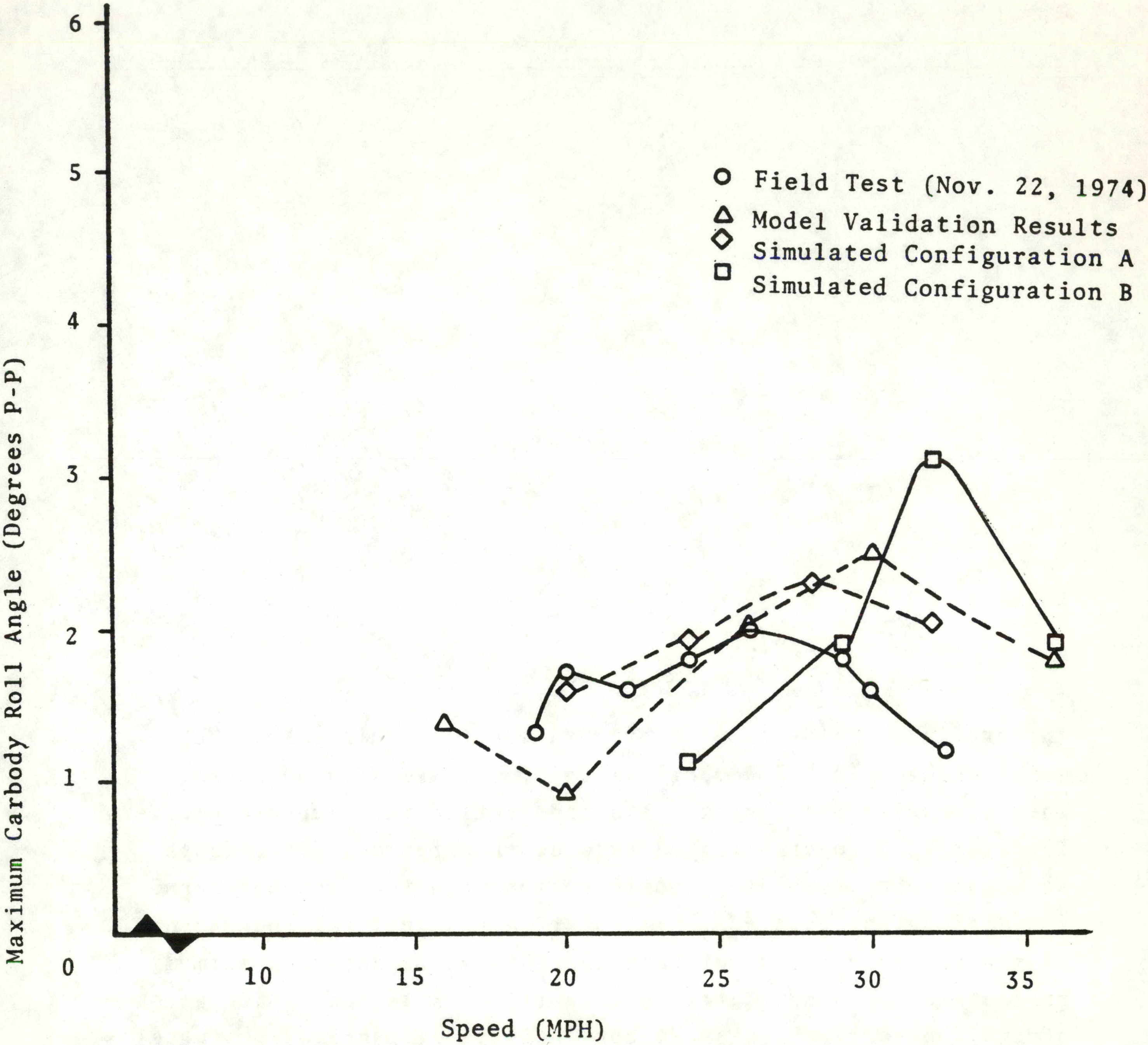


Figure 3-7. Roll Response Vehicle No. 39803

3.5.4 Simulated Configuration A

For this configuration, the load was increased to 228,000 pounds and its center-of-gravity to 85.4 inches above the car deck. This resulted in a slight decrease in roll amplitude and critical speed as compared to the validation. Aagin, no wheel lift was predicted by the model and this configuration is well within the amanded AAR specification.

3.5.5 Simulated Configuration B

The load for this configuration was 164,000 pounds and its center-of-gravity was 82 inches above the car deck. As shown in Figure 3-7, the roll response of this configuration was the highest of the three configurations tested at 3.1 degrees. The critical speed occurred at 32 mph and no wheelift was experienced. The roll stability of this configuration is well within the amended AAR specification.

3.6 VEHICLE NO. 39837

3.6.1 Vehicle Description

This vehicle (Figure 3-8) is a 150-ton, depressed center flat car made from a steel casting. Its load rating is 315,000 pounds. The car is 72 feet long, 9 feet wide, and has a light weight of 122,600 pounds. The vehicle uses four ASF Ride Control trucks that are grouped in pairs via a span bolster for each of the two trucks. Thus, each pair of two-axle trucks acts as a single, four-axle eight-wheel truck, with an axle spacing of 68 inches. The center-to-center distance of the truck combinations is 46 feet. The trucks use 6-inch x 11-inch roller bearings and one Stucki HS-6 hydraulic damper for each of the eight spring groups.

3.6.2 Field Test Results

Vehicle No. 39837 was tested for roll stability on 14 May 1975 with a load of 281,260 pounds at 78 inches above the car deck.

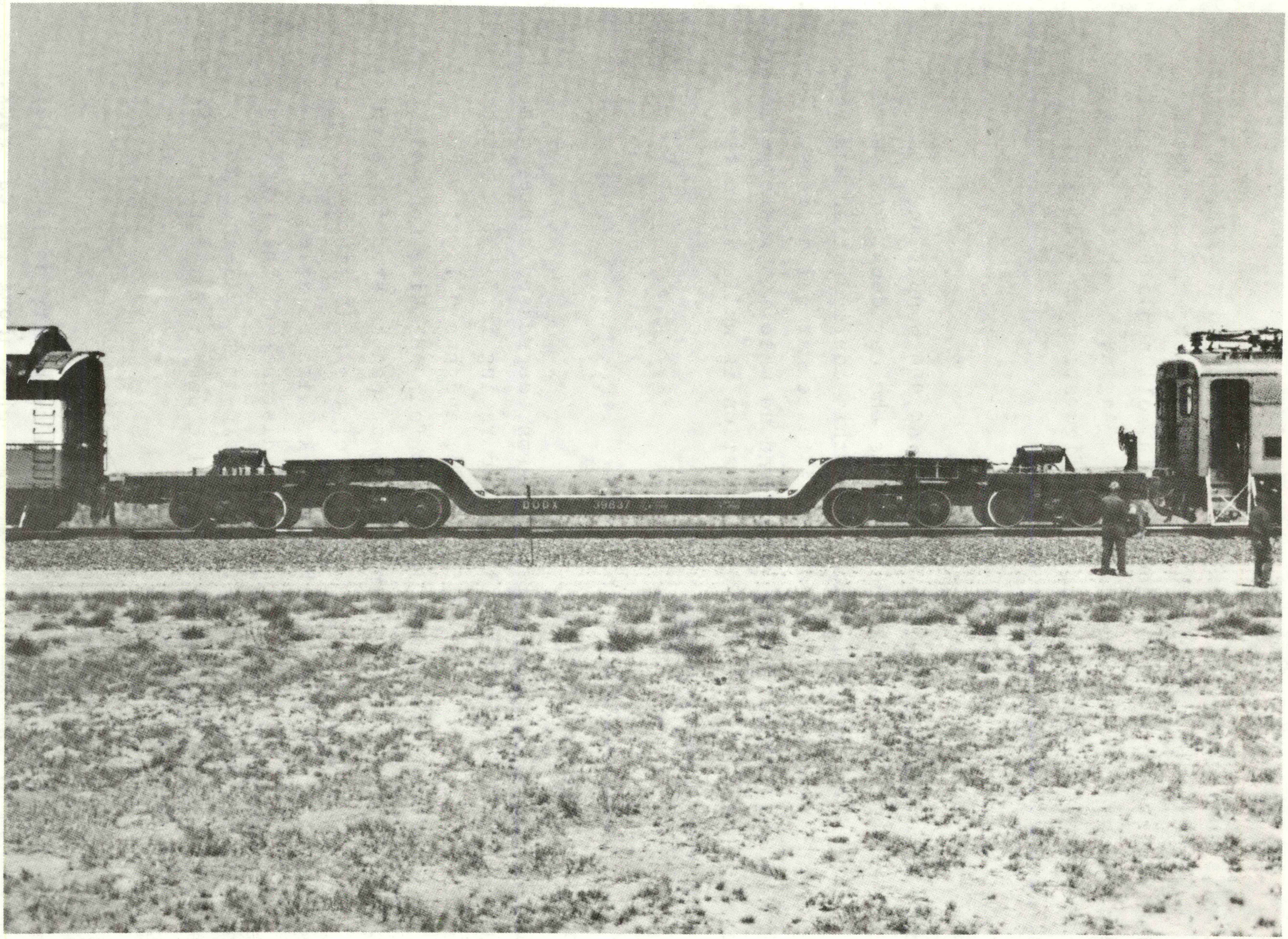


Figure 3-8. Vehicle No. 39837

Each of the spring groups contained six D-4 outer springs, six D-4 inner springs, and an HS-6 hydraulic stablizer. The table below lists the peak roll angle and wheel lift in these tests.

Speed (mph)	Peak Roll Angle (Degrees Peak-to-Peak)	Wheel Lift (Inches)
5	0.9	0
10	1.2	0
12	1.3	0
14	1.4	0
16	1.7	0
18	2.5	0
20	2.4	(minor)
22	1.8	(minor)
24	1.6	0
26	1.4	0
28	1.2	0
30	1.0	0
35	0.8	0

3.6.3 Model Validation Results

The field tested configuration was also simulated in the computer model for validation purposes. The results of this model validation run are shown in Figure 3-9 together with the previous field test results and optimum simulated configuration results. As can be seen, the model and field test results are in good agreement. Both show a resonant speed of 18 mph and resonant peak roll angles of 3.0 degrees and 2.5 degrees for the model and field tests, respectively. As was the case for the 39803 vehicle, a higher roll angle predicted by the model anticipated end results from the worst-case simulation of the four-axle trucks (refer to Section 2.3). Wheel lift in both cases was negligible and was therefore not plotted. Thus, this configuration satisfied the roll stability criteria. The close agreement

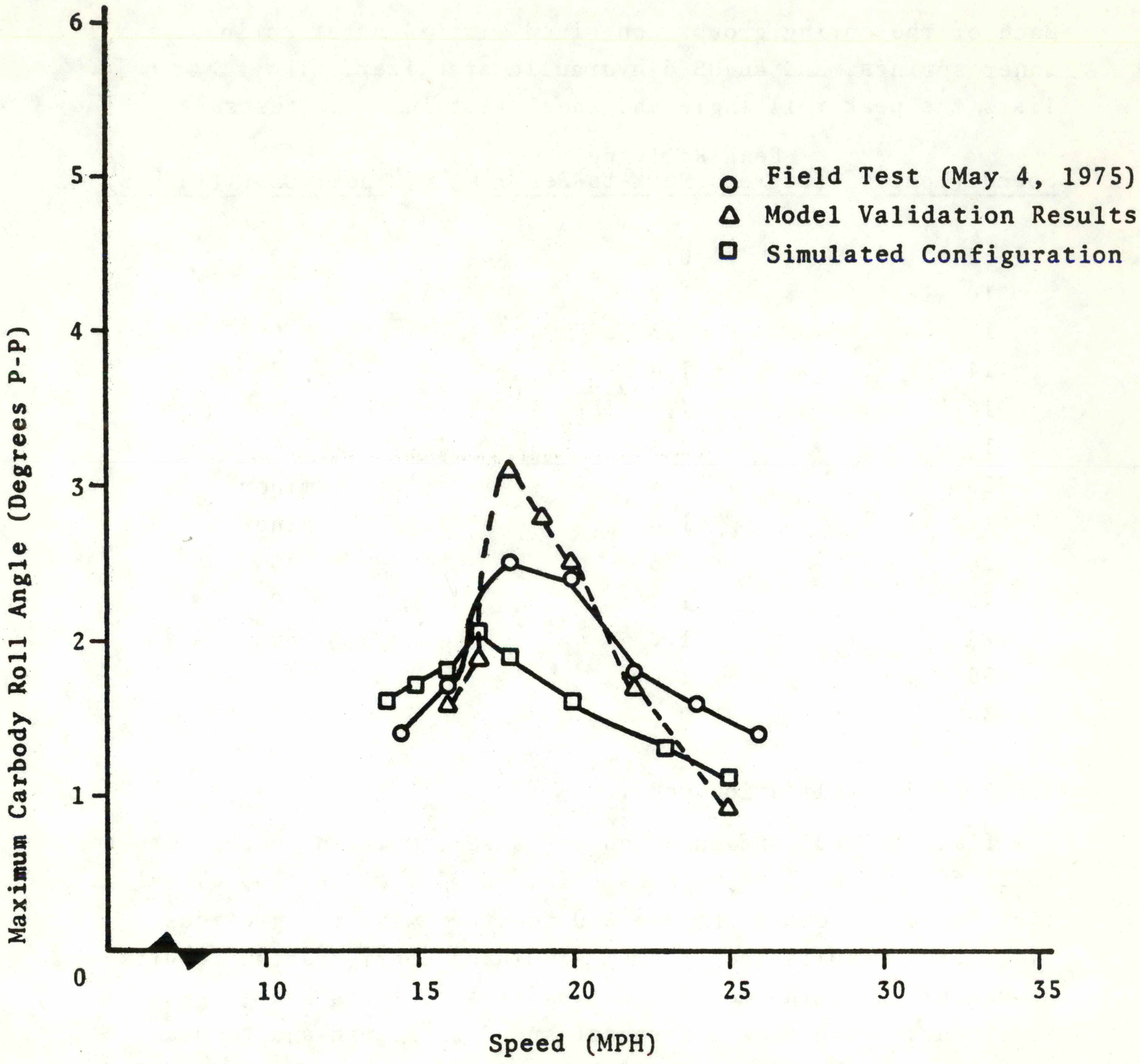


Figure 3-9. Roll Response Vehicle No. 39837

between model and field test results established the validity of the computer model for this vehicle and its usefulness for examining the roll stability of other configurations.

3.6.4 Simulated Configuration

This configuration differed from the validation case in that the load was 30,000 pounds less at a center-of-gravity height of 76 inches above the car deck. The simulated peak roll angle versus speed is plotted in Figure 3-9 along with the model and field test curves for the previous configuration. The peak roll angle for the new configuration is smaller (two degrees) and occurs at a slightly lower speed (17 mph). Wheel lift was again negligible. Thus, the reduction of load and load center-of-gravity for this vehicle produced improved response and no difficulties in meeting the roll stability criteria.

4.0 ANALYSIS OF SIMULATION RESULTS

4.1 GENERAL

To aid in evaluating the computer simulation results, including the degree of correlation with field test results, it is useful to first analyze the track input functions for the various configurations. Even though the track perturbations themselves are the same for all configurations, the effective track roll and torsional inputs are a function of truck center spacing and wheel base. This will be shown in Section 4.2. These inputs will be estimated for the various configurations in order to gain a better understanding of the simulated results, particularly where those results are at odds with field test results.

4.2 SIMPLIFIED ANALYSIS OF TRACK INPUT

Figure 4-1 illustrates the sine wave representation of the half-staggered rails and the resultant roll input β_1 produced on a two-axle truck of axle spacing B. (For simplicity, the gradual transition factor y/L for the first track input cycle has been omitted.)

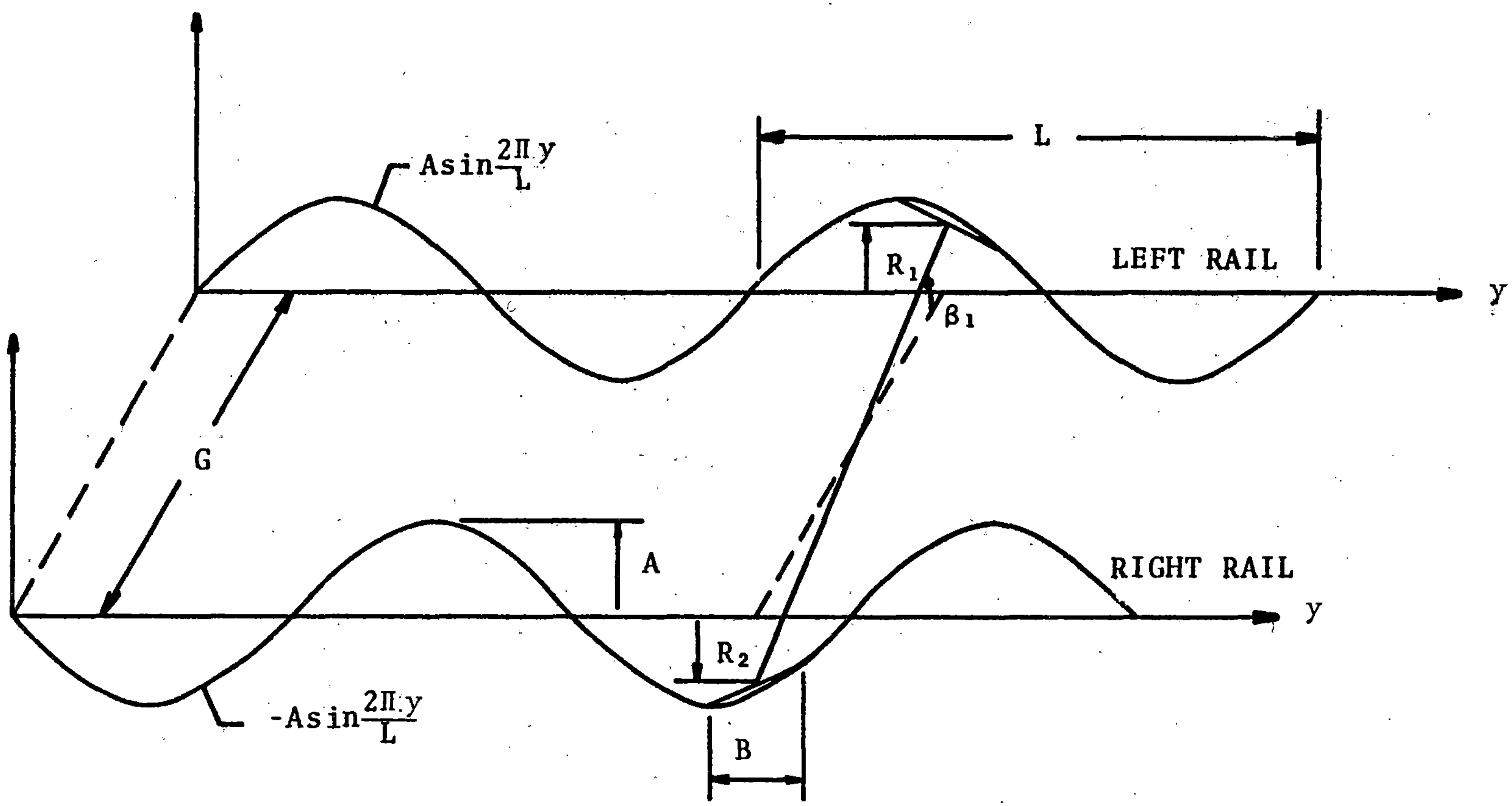
If y denotes the track position of the front truck center and the restriction is made that $A \ll L$, then the truck profile inputs R_1 and R_2 are simply

$$R_1 = \frac{1}{2}\left[A \sin \frac{2\pi}{L}\left(y - \frac{B}{2}\right) + A \sin \frac{2\pi}{L}\left(y + \frac{B}{2}\right)\right]$$

$$R_1 = A \sin \frac{2\pi y}{L} \cos \frac{\pi B}{L} \tag{17}$$

$$R_2 = -\frac{1}{2}\left[A \sin \frac{2\pi}{L}\left(y - \frac{B}{2}\right) + A \sin \frac{2\pi}{L}\left(y + \frac{B}{2}\right)\right]$$

$$R_2 = -A \sin \frac{2\pi y}{L} \cos \frac{\pi B}{L} \ . \tag{18}$$



G = Gage

B = Truck Axle Spacing

β_1 = Truck Input Roll Angle

L = Length of Rail Section

Figure 4-1. Track Input Roll Angle Produced by Half-Staggered Rails

Making the small angle assumption, limiting A<<G, the roll angle β_1 of the front truck is then given by

$$\beta_1 = \frac{R_1 - R_2}{G} = \frac{2A}{G} \sin \frac{2\pi y}{L} \cos \frac{\pi B}{L} \quad . \tag{19}$$

We can utilize Equation (19) to obtain the roll angle β_2 of the rear truck by replacing y by y - D, where D is the truck center spacing. Thus,

$$\beta_2 = \frac{2A}{G} \sin \frac{2\pi}{L} (y - D) \cos \frac{\pi B}{L} \quad . \tag{20}$$

Let β represent the average track roll input to the freight car. Then,

$$\beta = \frac{1}{2} (\beta_1 + \beta_2)$$

$$\beta = \frac{A}{G} \cos \frac{\pi B}{L} \left[\sin \frac{2\pi y}{L} + \sin \frac{2\pi}{L} (y - D)\right]$$

$$\beta = \frac{A}{G} \cos \frac{\pi B}{L} \left[\sin \frac{2\pi y}{L} \left(1 + \cos \frac{2\pi D}{L}\right) - \cos \frac{2\pi y}{L} \sin \frac{2\pi D}{L}\right] \tag{21}$$

We can also define an average torsional input γ to the freight car as

$$\gamma = \beta_1 - \beta_2$$

$$\gamma = \frac{2A}{G} \cos \frac{\pi B}{L} \left[\sin \frac{2\pi y}{L} - \sin \frac{2\pi}{L} (y - D)\right]$$

$$\gamma = \frac{2A}{G} \cos \frac{\pi B}{L} \left[\sin \frac{2\pi y}{L} \left(1 - \cos \frac{2\pi D}{L}\right) + \cos \frac{2\pi y}{L} \sin \frac{2\pi D}{L}\right] . \tag{22}$$

Equations (21) and (22) allow us to interpret the effective roll and torsional inputs to the freight car as a function of truck center spacing D and wheel base B. Wheel base B has the effect of reducing both roll and torsional inputs by the factor $\cos\left(\frac{\pi B}{L}\right)$. However, truck center spacing D has the most dramatic effect. Thus, for example, letting D = L reduces the torsional input γ to zero while maximizing average roll input angle β. Conversely, letting $D = \frac{3}{2}L$ (or L/2) reduces roll angle β to zero while maximizing the torsional input angle γ. Figure 4-2 illustrates the normalized roll and torsional inputs for all truck center spacing rail length ratios of intrest for a given wheel base.

4.3 MODEL VALIDATION

Initial attempts to validate the computer model for vehicle number 38444 were unsuccessful in that significant discrepancies existed between predicted roll response and field-measured roll response. In order to identify potential causes for these discrepancies, a series of parametric studies were performed to determine roll response sensitivity to parameter variation. At no time were parameters varied for the purpose of acquiring a best fit to field test results. The parametric studies, when supplemented with an analysis of system dynamics proved valuable in gaining an understanding of the rock and roll phenomenon and in identifying those parameters which had the most pronounced effect on roll dynamics. In addition to verifying established relationships between roll response and such parameters as load, height of center-of-gravity, and vertical spring stiffness it was determined that the location of the gib relative to the axle centerline had a significant effect on maximum carbody roll angle and wheel lift. In addition, it was determined that (for lightly loaded vehicles) the Stucki hydraulic stabilizer (HS-6) provided an effective damping coefficient significantly less than the specified value. Further investigation revealed that the combined effect of light load and D-4 springs resulted in the damping device

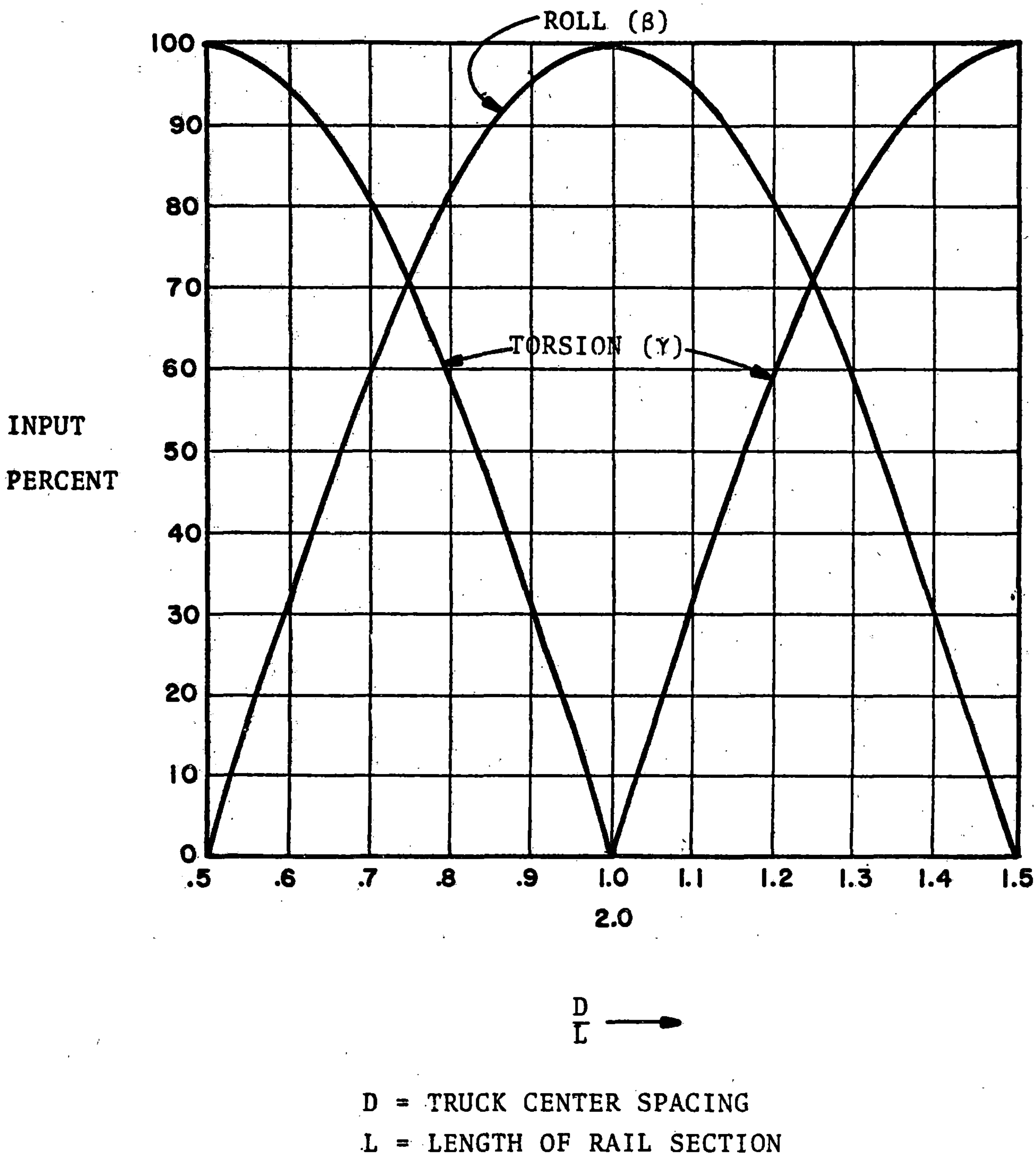


Figure 4-2. Normalized Roll and Torsional Inputs to Freight Car as a Function of Truck Center Spacing

operating much of the time within a dead band of the damper stroke (see Section 2.2.4). An important conclusion of the initial validation effort is that the performance of vehicle number 39551 can be significantly improved by installing a hydraulic stabilizer which operates over the full stroke of the damper. Corrections to the computer model and input parameters made at the conclusion of the parametric study and analysis effort resulted in near perfect model validation for this vehicle.

Validation of vehicle number 39837 introduced a new problem; that of modeling the 4-axle truck and span bolster. As was discussed in Section 2.3, a worst-case approximation was made based on a two-axle truck having equivalent mass and spring stiffness. Based on the conclusion of Section 4.2, the shorter wheelbase, two-axle approximation provides greater input to the vehicle than the longer 4-axle truck and thus the term worst-case approximation.

The validation of the computer model for the 39837 vehicle as shown in Figure 3-9 is quite good. As was expected, based on the preceding discussion, the predicted roll angle was greater than that of the field results by approximately 25 percent while predicted critical speed and wheel lift agreed well with field results.

The truck center spacing to rail length ratio (D/L), discussed in Section 4.2, for the 39551 and 39837 vehicles is calculated to be 1.0 and 1.18, respectively. Figure 4-2 indicates that the rail input for these ratios is primarily roll and conversely torsional inputs are quite low. The 39803 vehicle has a D/L ratio of 1.36. From Figure 4-2, this ratio corresponds to a significant torsional input to the vehicle based on the 39-foot perturbation and reduced roll excitation.

As discussed in Section 2.3, the representation of the flexible car as two half-bodies connected by a torsional spring has limited capability in predicting roll stability particularly for long flexible carbodies where torsional input to the vehicle is high. Specific problems are:

- The torsional spring constant is not an effective parameter, i.e.,it has no physical significance. The selection of such a parameter is based on relatively crude approximations and the margin for error is high. Incorrect selection of the torsional spring constant may result in errors in peak roll amplitude, critical speed, and possibly produce attenuated responses at various speeds, due to the relative phase between carbody roll and torsion.

- The model predicts roll angles at the center-of-gravity of the half carbody while field results are measured over the bolster. Thus predicted and measured roll angles may differ significantly when the car experiences appreciable torsion.

- Modeling the torsional response as a single valued roll contribution over the total length of the half carbody is only an approximation of the true mode shape. Additional degrees of freedom are required to more accurately model the torsional response where this response is large.

Comparing the validation and field results in Figure 3-7 for the 39803 vehicle, it can be seen that both the critical speed and maximum roll amplitude differ by 15 and 20 percent, respectively. Also note that at 20 mph the validation results indicate a distinct null which may be attributed to the interaction of torsion and roll modes as was discussed previously. Although the degree of confidence is somewhat less than that for the 39837 and 39551 due to the large torsional input, the validation results were judged adequate to simulate two additional configurations.

The vehicle number 38444 was the only one of four vehicles simulated for validation purposes which produced poor results. Although time and funding limitations on the project prevented an in-depth study to determine the exact causes for the discrepancies, an evaluation of model capability to simulate the characteristics of this vehicle indicated no limitation which might cause such poor correlation with field results. It must therefore be assumed that one or more critical parameters were well outside tolerance or that these parameter values were reported incorrectly.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The conclusions that can be drawn from ENSCO's DODX computer modeling effort fall into two main categories. The first concerns the validity of the computer model as modified by ENSCO, and its potential for use in evaluating roll stability of freight cars. Included in this category are the identification of those little-known physical characteristics that were found to be important in obtaining a valid simulation. The second category of conclusions deals with the evaluation of DODX vehicle roll stability for those configurations investigated in the simulation effort. In particular, the effect on roll stability of certain vehicle characteristics was confirmed or established.

One major conclusion from the study is that the final computer model can accurately simulate the rock and roll response of conventional freight cars with two-axle trucks provided that these cars are not prone to twist about the longitudinal axis.

The computer model can be used for freight cars with three or four-axle trucks, but with a reduced accuracy in predicting peak roll angle response and wheel lift. The capability of the model predicting resonant speed would still be quite good.

The computer model is not effective for modeling the rock and roll response of very long and/or flexible freight cars. Freight cars whose truck center distance is greater than 1.3 times the 39-foot length of rail sections will receive a substantial torsional input from half-staggered rails (refer to Section 4.2). This combined with the torsional flexibility of very long cars can result in a substantially modified rock and roll response. The computer model lacks the necessary degrees of freedom to accurately model the interaction of the roll and torsional response when these responses are large.

For those vehicles whose roll response can be effectively simulated by the computer model, it is still necessary to accurately specify the vehicle inertial and geometric properties in order to obtain a valid simulation. It is also necessary to specify flexural stiffness coefficients at the junction of the car half-bodies that will effectively account for actual vehicle flexibility. This is particularly true in torsion since the vehicle torsional response can substantially affect rock and roll stability.

It was discovered that under certain circumstances, the Stucki hydraulic stabilizer has a deadband in which the damping force is zero. In order to simulate damper operation accurately, it is necessary to incorporate this deadband in the simulation model. This is particularly true for lightly loaded cars in which the dampers would operate much of the time in this range of zero damping force.

Another little-known characteristic which was determined to be quite important in its effect on roll stability is the vertical height of the gib contact relative to that of the axle centerline. Gib contact that occurs above the axle has a negative effect on roll stability, and vice-versa for gib contact that occurs below the axle. However, the negative (positive) effect on roll stability quickly reaches a limit and further increases in the distance of gib contact above (below) the axle have little further effect.

The computer simulation studies of DODX vehicle roll stability also confirmed or established the following cause-effect relationships:

- Softer truck suspensions generally result in improved roll stability.

- Lowering the vehicle center-of-gravity improves its stability.

- The Stucki hydraulic damper improves vehicle roll stability.

- Increased truck-axle spacing reduces the effective track input from half-staggered rails and thus reduces the vehicle roll response.

- The truck center spacing has a dramatic effect on the roll and torsional inputs transmitted to the vehicle from half-staggered rails, and thus has a marked effect on vehicle rock and roll response.

5.2 RECOMMENDATIONS

In order to obtain increased benefits from the computer simulation of freight car roll stability, the following recommendations are made for future studies:

- Investigate the adequacy of the computer model for very flexible car bodies; determine requirements for additional degrees of freedom to obtain valid rock and roll response.

- Determine whether additional degrees of freedom are required for three and four-axle trucks in order to obtain satisfactory accuracy of vehicle roll amplitude response.

- Perform parametric studies to determine specific effects of vehicle and component characteristics on roll stability; determine the need for further investigation of promising design changes.

- Utilize simulation studies as a screening device for additional field tests; these studies could be used to recommend field tests only for those vehicle configurations that showed up as marginally stable in the simulation studies.

6.0 REFERENCES

1. Tse, Y.H., "Method of Analysis for the Dynamic Behavior of Flexible Body Railroad Freight Car," Master's Thesis at Illinois Institute of Technology, Chicago, IL, Dec 1974.

2. Martin, G.C. and Tse, Y.H., "Parametric Studies on a Railroad Freight Car Mathematical Model," ASME paper 75-WA/RT-11, presented at the ASME Winter Annual Meeting in Houston, Texas, Nov 30 - Dec 4, 1975.

3. Goldberg, H., Classical Mechanics, Addison-Wesley Publishing Co., Inc., Reading, MA, 1950.

4. Wiebe, D., "Damping Requirements to Control Vertical and Roll Motion of Freight Cars," presented at the ASME Annual Meeting, November 1974.

5. Margiros, D.G., "Methods for Solutions of Nonlinear Ordinary Differential Equations, Applications," G.E. TM 9159-1, September 1968.

6. Harmonic Roll Series, Vol. 4, Torsional and Flexural Car Stiffness Characteristics, AAR-FRA-RPI-TDA Research Program on Track-Train Dynamics.

7. ENSCO, INC., "Test Results Summary Report for DODX Railcar Stability Test," FRA Contract DOT-FR-64113, 30 December 1976.

APPENDIX A

AMENDED AAR SPECIFICATIONS D-65 - TESTING SPECIAL DEVICES TO CONTROL STABILITY OF FREIGHT CARS

APPENDIX A

TESTING SPECIAL DEVICES TO CONTROL STABILITY OF FREIGHT CARS AMENDED AAR SPECIFICATIONS D-65

I. Scope. These specifications cover testing and performance requirements for trucks or other special devices to control car stability.

II. Test Conditions. The tests shall be conducted using rail cars specified. This test will be run over a track section as specified below.

A. Description of the test cars.

1. Car shall be loaded to specified loads to obtain the desired center of gravity.

2. Where conventional side bearings are used the side bearing clearance shall be 3/16 inches minimum to 1/4-inch maximum.

3. Outside wheel rims to be painted white.

B. Test track conditions.

1. The track is to be laid to 4 feet 8 1/2 inches gage with 39-foot rails of 100 pound section or heavier with joints uniformly staggered at approximately 19 feet and 6 inches, on a good tie and ballast support. Outside face of high rail head to be painted white.

2. The tangent track for the distance in which the test trains will be operated approaching the shimmed joints shall have the joint condition and crosslevel maintained to avoid excessive car roll.

3. The rail shall be shimmed opposite 20 consecutive joints to within 1/16 inch of 3/4 inch low joint condition. A re-check of the crosslevel shall be made as often as required to maintain the test conditions uniformly.

III. Instrumentation. The test car shall be fitted with the following instrumentation to check various conditions developed in the test car during the runs over the test track:

A. A vertical reference gyro to be placed on the longitudinal center line of the car, preferably on the center sill, near the body bolster of the car to measure angular displacement of the carbody.

Specification for Vertical Reference Gyro:

1. Roll angle minimum ± 15 degrees.
2. Erection rate 2 degrees to 8 degrees per minute.
3. Accuracy 0.15 degrees of true vertical.
4. Pickoff resolution 1/8-degree or better.
5. Potentiometer linearity 1 percent or better.

B. Accelerometers to measure angular accelerations about the roll, yaw and pitch axes and linear accelerations about the vertical, lateral and longitudinal axes are to be mounted on the carbody. Specifications for these accelerometers are:

1. Roll accelerometer range ± 5 radians/second^2.
2. Yaw and pitch accelerometer range ± 1 radian/second^2.
3. Vertical, lateral and longitudinal accelerometer range ± 1 g.
4. Accuracy ± 1 percent of full scale.

C. Cabling potentiometers to measure spring group and carbody to bolster deflection. Specifications are:

1. Linearity of 1 percent or better.
2. Range of ± 5 inches.

D. Motion picture camera (or equivalent) shall be installed to view the lead wheel of the lead truck and the rear wheel of the rear truck and shall be capable of showing any wheel lift or wheel climb in relation to the rail.

IV. Running Tests.

A. Test train consist. The test train shall consist of the following locomotive and cars in the order presented:

1. Locomotive.
2. Instrumentation Car.
3. Observation Car (optional).
4. Test car or cars including base (control car).
5. Trailing car which should be a loaded car of at least 77-ton capacity.
6. Caboose or other car to complete train consist if desired.

B. The test train shall be run over the prepared section of track at speeds beginning at approximately 5 mph and 10 mph and then running in increments of 2 mph through the critical speed up to a limit of about 35 mph. The speeds shall be accurately measured by instrumentation in the instrument car. It may be desireable to repeat runs at any speed, particularly within the critical speed range to establish precisely the action of the car in the critical range.

V. Specifications.

A. The test car when operated under the conditions of "IV. Running Tests" shall not show excessive roll, wheel lifting or derailment tendency. The limits and definitions of these parameters are as follows:

1. The total roll angle as determined by the gyro shall not exceed 6 degrees.

2. Wheel lifting shall be defined as "slight" up to 1/2 inch; "small" from 1/2 inch to 1 inch; "medium" from 1 inch to 2 inches; "large" above 2 inches. Wheel lifts if developed shall be restricted to "slight".

3. The derailment tendency is determined by the action whereby the flange rides on the head of the rail for any distance during the test. This shall not be permitted and will be cause for rejection of any device.

B. The data developed from instrumentation will be used to determine the roll angle, wheel lift and derailment tendencies of the car.

APPENDIX B

FINAL PROGRAM LISTING

```
RDS-500 FORTRAN4 REV. F 04/29/79
      PROGRAM MRB
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON/T1/Y(40),F(40),SAVEY(40),DTHALF
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON/T72/TEM2,TEM3,TEM4,TEM5,TEMPI,TEMPJ,TEMP,TEM6,TEM7,SINTH,
     C COSTH,PTEMP,THETA
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *            SFVER,THRESH
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *           GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      COMMON/ADD5/ADAR1
      DATA PI,PIHALF,PIX2/3.1416,1.5708,6.2832/
S        DATE  12,5,5
1111  CONTINUE
S        LOAD BLKDMR
      DO 5 I=1,4
      AKS(I)=0.
      POW(I)=0.
      POWMAX(I)=0.
    5 CONTINUE
      REWIND 8
      REWIND 9
      REWIND 10
      CALL MRBIN
      READ(2,97) ADAR1
   97 FORMAT(F10.5)
      CALL MRBS12
      READ(2,990) NRP,NDJ,IOPT
990   FORMAT(3I5)
      DTHALF=DT/2.
      PTEMP=PIX2*NDJ
      COTEMP=COEFF*SFLAT
      SLOPE=4.*S
      YNTRCP=SLOPE/2.
      BL2=B/2.
      IF(NRP.EQ.1) GO TO 91
      WRITE(3,992) NDJ
992   FORMAT(' # OF DEPRESSION JOINTS FOR BOUNCING MODE SIMUL.=',I2)
```

```
      PH1=2.*PH1
      PH2=2.*PH2
      PH3=2.*PH3
      PH4=2.*PH4
      OM=2.*OM
91    CONTINUE
      II=0
      JT=0
      P=0.
      IF (KODE) 49,49,501
  501 CALL RESET
      KODE=KODE-1
      P=T
49    CALL MRBL1
   50 CONTINUE
      II=II+1
  500 CALL RUNG2(40,P,JT)
      IF (JT) 510,100,510
  510 CONTINUE
      CALL MRBS22(P,JT)
      GO TO (512,511),NRP
511   CALL MRB2A2(P,NDJ,JT)
512   CALL MRBS32
      CALL SPCON
      CALL DAM2
   55 CALL ACCEL
      DO 602 I=1,10
  602 F(I)=VEL(I)
      F(11)=VEL(12)
      F(12)=VEL(13)
      DO 604 I=13,20
      J=I+2
  604 F(I)=VEL(J)
      DO 702 I=21,30
      J=I-20
  702 F(I)=ACC(J)
      F(31)=ACC(12)
      F(32)=ACC(13)
      DO 703 I=33,40
      J=I-18
  703 F(I)=ACC(J)
      GO TO 500
  100 CONTINUE
      IF (II-NT) 150,300,300
  150 CONTINUE
      T=T+DT
      GO TO 50
  300 T=T+DT
      CALL RESET
C        WRITE UNIT 9 FILE
      CALL MRBS4
C        WRITE UNIT 10 FILE
      CALL MRBS5
      II=0
      IF (T-DTMAX) 50,200,200
200   CALL MEND
      STOP
      END
NO ERRORS
SYM3 REV.G
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE MRBIN
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
C OLD COMMON/T5/V,AL,S,D,B
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
C OLD COMMON/T6/DT,DTMAX,NT,KODE
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
C OLD COMMON /ADD/XSC(4),POGC,COEFF
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *            SFVER,THRESH
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *           GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *        POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *        DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      READ(2,1000) ID
1000  FORMAT(40A2)
      READ (2,1001) AIX1,AIY1,AIZ1,AIX2,AIY2,AIZ2,AIY3,AIY4,AIY5,AIY6,
     *              AM1,AM2,AM3,AM4,AM5,AM6,
     *              P1,P2,P3,P4,BE1,BE2,BE3,BE4,
     *              G1,G2,G3,G4,W1,W2,W3,W4,
     *              S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,
     *              C1,C2,C3,C4,B1,B2,D1,D2,
     *              (XSC(I),I=1,4),CW1,CW2,CW3,CW4,D1PI,D2PI
 1001 FORMAT (8F10.8/2F10.8/6F10.8/3(8F10.8/),8F10.8/8F10.8,/,2F10.8)
      ZS1=S1
      ZS2=S2
      ZS3=S3
      ZS4=S4
      READ (2,1010) V,AL,S,D,B
 1010 FORMAT (5F10.4)
      READ (2,1011) (GKP(I),I=1,4),
     *              (GKBE(I),CDBE(I),GDBE(I),I=1,4),
     *              (GKG(I),CDG(I),GDG(I),I=1,4),
     *              (GKS(I),CDS(I),GDS(I),I=1,4),
     *              (GKW(I),CDW(I),GDW(I),I=1,4),
     *               (GKWX(I),CDWX(I),GDWX(I),I=1,4),
     *             (GDSTK(I),I=1,4),STKTHR,
     *               T12,B12Z,B12X,D12,T12X,T12Z
1011  FORMAT(4(F10.0,/),20(F10.0,I1,9X,F10.0/),5F10.0,/,6E10.3)
      READ (2,1018) POGC,SFLAT,SFVER,COEFF,THRESH
 1018 FORMAT (5F10.8)
```

```
      READ (2,1003) (DIS(I),I=1,22)
      READ (2,1003) (VEL(I),I=1,22)
 1003 FORMAT (2(8F10.0/),6F10.0)
      READ (2,1005) DT,DTMAX,NT,KODE
 1005 FORMAT (2F10.5,2I5)
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

RDS-500 FORTRAN4 REV. F 04/29/79

```
      SUBROUTINE MRBS12
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON/T1/Y(40),F(40),SAVEY(40),DTHALF
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON/T72/TEM2,TEM3,TEM4,TEM5,TEMPI,TEMPJ,TEMP,TEM6,TEM7,SINTH,
     C COSTH,PTEMP,THETA
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *           GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *            SFVER,THRESH
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S        DATE  12,5,5
C        PH1 = 90 DEG IN RADS
      PH1=PI
C        PH2 - PORTION OF SIN IN RAIL LENGTHXTRUCK CENTER DISTANCE
      IF(AL.EQ.0.) STOP AL=0
      TEM1=PI/AL
      PH2=TEM1*D*2.
C        PH3 - 90 DEG + PH2
      PH3=PH1 + PH2
C        PH4 - PORTION OF SIN IN RAIL LENGTHXWHEEL BASE LENGTH
      PH4=TEM1*B*2.
      OM=TEM1*V   *2.
      TEM2=1. + COS(PH4)
      TEM3=SIN(PH4)
      TEM4=COS(PH2)
      TEM5=SIN(PH2)
      THETA=ATAN((SIN(PH1)+SIN(PH1-PH4)+SIN(PH4))/(1.+COS(PH4)-COS(PH1)
     * -COS(PH1-PH4)))
10    SINTH=SIN(THETA)
      COSTH=COS(THETA)
C    TEM2=COS(PH4)
      TEM2=TEM2-1.
      TEM6=TEM2*TEM4-TEM3*TEM5
      TEM7=TEM2*TEM5+TEM3*TEM4
      SHALF=S/2.
      SQUART=S/4.
C        RECTIFIED SINE
C     PQ1=ABS(SINTH)
C     PQ1=(PQ1+ABS(SINTH*TEM2-COSTH*TEM3))*SHALF
C        TRUE SINE
```

```
      PQ1=SINTH+SINTH*TEM2-COSTH*TEM3
      PQ1=PQ1*SHALF
      T=0.
      DO 56 I=1,4
      DG(I)=0.
      GO TO 56
   57 DG(I)=GDG(I)
   56 CONTINUE
      TEMP18=-(AM1+AM3+AM5)*G/(GKW(1)+GKW(2))
      DIS(18)=DIS(18)+TEMP18
      TEMP21=-(AM2+AM4+AM6)*G/(GKW(3)+GKW(4))
      DIS(21)=DIS(21)+TEMP21
      TEMP12=TEMP18-((AM1+AM3)*G-DG(1)-DG(2))/(GKG(1)+GKG(2))
      DIS(12)=DIS(12)+TEMP12
      TEMP15=TEMP21-((AM2+AM4)*G-DG(3)-DG(4))/(GKG(3)+GKG(4))
      DIS(15)=DIS(15)+TEMP15
      BKP1=GKP(1)+GKP(2)
      BKP2=GKP(3)+GKP(4)
      A(1,1)=-BKP1-B12Z
      A(1,2)=B12Z
      A(1,3)=-BKP1*D1 + B12Z*D1PI
      A(1,4)=B12Z*D2PI
      A(1,5)=AM1*G-BKP1*TEMP12
      A(2,1)=B12Z
      A(2,2)=-BKP2-B12Z
      A(2,3)=-D1PI*B12Z
      A(2,4)=BKP2*D2 -D2PI*B12Z
      A(2,5)=AM2*G-BKP2*TEMP15
      A(3,1)=-BKP1*D1 + B12Z*D1PI
      A(3,2)=-B12Z*D1PI
      A(3,3)=-BKP1*D1**2.-T12X -B12Z*D1PI**2
      A(3,4)=T12X -B12Z*D1PI*D2PI
      A(3,5)=-BKP1*D1*TEMP12
      A(4,1)=-B12Z*D2PI
      A(4,2)=B12Z*D2PI-BKP2*D2
      A(4,3)=-T12X +B12Z*D1PI*D2PI
      A(4,4)=BKP2*D2**2.+T12X + B12Z*D2PI**2
      A(4,5)=-BKP2*D2*TEMP15
      CALL GAUSS (A,X,4)
      DIS(2)=DIS(2)+X(1)
      DIS(7)=DIS(7)+X(2)
      DIS(4)=DIS(4)+X(3)
      DIS(9)=DIS(9)+X(4)
      DO 605 I=1,10
  605 Y(I)=DIS(I)
      Y(11)=DIS(12)
      Y(12)=DIS(13)
      DO 606 I=13,20
      J=I+2
  606 Y(I)=DIS(J)
      DO 705 I=21,30
      J=I-20
  705 Y(I)=VEL(J)
      Y(31)=VEL(12)
      Y(32)=VEL(13)
      DO 706 I=33,40
      J=I-18
  706 Y(I)=VEL(J)
      DO 800 I=1,4
      R(I)=0.
```

```
      RD(I)=0.
800   CONTINUE
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE GAUSS (A,X,N)
      DOUBLE PRECISION A,TEMP,R
      DOUBLE PRECISION TA(5,5)
      DIMENSION A(5,5),X(4)
      DO 4 I=1,4
      DO 4 J=1,4
      TA(I,J)=A(I,J)
4     CONTINUE
      NP1=N+1
      DO 20 I=2,N
      IM1=I-1
      TEMP=A(IM1,IM1)
      DO 20 J=I,N
      IF(TEMP.NE.0.) GO TO 1
      PRINT 102,TEMP,IM1
102   FORMAT(1X,E15.8,I2)
      PRINT 100,TA
      PRINT 100,A
100   FORMAT(5E15.8)
    2 CONTINUE
      DO 21 M=I,N
      IF (A(M,IM1)) 3,21,3
    3 DO 22 MM=IM1,NP1
      SAVE=A(M,MM)
      A(M,MM)=A(IM1,MM)
   22 A(IM1,MM)=SAVE
   21 CONTINUE
      WRITE (3,199)
 1000 CONTINUE
S         DUMP  =LST,=1,X'7000',X'B000'
      CALL MEND
    1 R=A(J,IM1)/TEMP
      DO 20 K=I,NP1
   20 A(J,K)=A(J,K)-R*A(IM1,K)
      DO 30 I=2,N
      K=N-I+2
      IF(A(K,K).EQ.0.) PRINT 101,A(K,K)
101   FORMAT(' DIAG 0 IN BACK SOL ',E15.8)
      R=A(K,NP1)/A(K,K)
      DO 30 J=I,N
      L=N-J+1
   30 A(L,NP1)=A(L,NP1)-R*A(L,K)
      DO 40 I=1,N
      X(I)=A(I,NP1)/A(I,I)
   40 CONTINUE
      RETURN
  199 FORMAT (' SINGULAR COEFF. MATRIX')
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE RESET
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T1/Y(40),F(40),SAVEY(40),DTHALF
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
C OLD COMMON/T6/DT,DTMAX,NT,KODE
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
C OLD COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,Q,OM
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *       ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      IF (KODE) 10,10,20
8     FORMAT(8E15.8)
   10 WRITE(8,8)(Y(I),I=1,40),(F(I),I=1,40),(R(I),I=1,4),(POW(I),I=1,4)
     *       ,(RD(I),I=1,4),T
      ENDFILE 8
      REWIND 8
      RETURN
   20 READ(8,8)(Y(I),I=1,40),(F(I),I=1,40),(R(I),I=1,4),(POW(I),I=1,4)
     *       ,(RD(I),I=1,4),T
      WRITE(1,100)
100   FORMAT(' SWITCH TAPES PLEASE')
      PAUSE TAPE
      POG(1)=Y(16)-Y(11)+G1*(Y(17)-Y(12))
      POG(2)=Y(16)-Y(11)+G2*(Y(12)-Y(17))
      POG(3)=Y(19)-Y(13)+G3*(Y(20)-Y(14))
      POG(4)=Y(19)-Y(13)+G4*(Y(14)-Y(20))
      ZS1=S1-POG(1)
      ZS2=S2-POG(2)
      ZS3=S3-POG(3)
      ZS4=S4-POG(4)
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE MRBL1
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
C OLD COMMON/T5/V,AL,S,D,B
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
C OLD COMMON/T6/DT,DTMAX,NT,KODE
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
C OLD COMMON /ADD/XSC(4),POGC,COEFF
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *           SFVER,THRESH
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *           GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *        POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *        DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      WRITE(3,1000) ID,T,DTMAX
1000  FORMAT(1H1,46X,'DODX COMPUTER SIMULATION - VEHICLE MODEL',/,1X,
     *40A2, 2X,' RUN FROM TIME ',F8.5,' SECS TO TIME ',F8.4,' SECS')
      WRITE(3,1002) AIX1,AIX2,AIY1,AIY2,AIY3,AIY4,AIY5,AIY6,AIZ1,AIZ2
1002  FORMAT(40X,'CARBODY',8X,'BOLSTER',8X,'WHEELSETS',/,33X,3(4X,'FRONT
     *',3X, 'REAR'),/,6X,'MOMENT OF INERTIA',3X,'PITCHING',2F9.1,/,24X,
     *'ROLLING',1X,6F8.1,/,26X,'YAWING',2X,2F8.1)
      WRITE(3,1003) AM1,AM2,AM3,AM4,AM5,AM6
1003  FORMAT(6X,'MASSES (SLUGS)',14X,6F8.2)
      WRITE(3,1004) P1,P2,P3,P4,BE1,BE2,BE3,BE4
1004  FORMAT(51X,'FRONT',30X,'REAR',/,6X,'DISTANCES + LENGTHS',21X,'LEFT
     *',10X,'RIGHT',16X,'LEFT',10X,'RIGHT',/,8X,'CENTERPLATE RADIUS',14X
     *,2(F10.4,5X),2(5X,F10.4),/,8X,'SIDE BEARINGS TO CENTER',9X,2(F10.4,5
     *,5X),2(5X,F10.4))
      WRITE(3,10041) G1,G2,G3,G4,W1,W2,W3,W4
10041 FORMAT(          8X,'SUSPENSION GROUPS TO CENTER',05X,2(F10.4,5X
     *),2(5X,F10.4),/,8X,'HALF OF GAGE',20X,2(F10.4,5X),2(5X,F10.4))
      WRITE(3,10042) S1,S2,S3,S4
10042 FORMAT(8X
     *,'C.G. WHEELSETS TO SIDE SPRINGS',2X,2(F10.4,5X),2(5X,F10.4))
      WRITE(3,1005) C1,C2,C3,C4,ZB1,ZB2,ZB3,ZB4
1005  FORMAT(8X,'C.G. WHEELSETS TO RAIL',10X,2(F10.4,5X),2(5X,F10.4),/,8X,'SIDE
     *X,'SIDE BEARING CLEARANCE',10X,2(F10.4,5X),2(5X,F10.4))
      WRITE(3,10051) (XSC(I),I=1,4),CW1,CW2,CW3,CW4
10051 FORMAT(8X,'GIB CLEARANCE',
     *          19X,2(F10.4,5X,),2(5X,F10.4),/,8X,'FLANGE CLEARANCE',16X
     *,2(F10.4,5X),2(5X,F10.4))
      WRITE(3,10052)B1,B2,D1,D2,D1PI,D2PI
```

```
10052 FORMAT(                         8X,'C.G. CARBODY TO C.G. BOLSTER',11X,
     *F10.4,25X,F10.4,/,8X,'C.G. CARBODY TO CENTERPLATE',12X,F10.4,25X,
     *F10.4,/,8X,'C.G. WHOLE CAR TO C.G. HALF CAR',8X,F10.4,25X,F10.4)
      WRITE(3,1006) POGC,D,B,AL,S
1006  FORMAT(8X,'SPRING GROUP CLEARANCE',35X,F10.4,/, 8X,'TRUCK CENTER T
     *O TRUCK CENTER',29X,F10.4,/, 8X,'WHEEL BASE',47X,F10.4,/,8X,'RAIL
     *LENGTH',46X,F10.4,/,8X,'MAXIMUM CROSS LEVEL',38X,F10.4)
      WRITE(3,1007) GKP,GKBE
1007  FORMAT(6X,'SPRING CONSTANTS',/,8X,'CENTER PLATE VERTICAL',11X,
     * 2(F10.0,5X),2(5X,F10.0),/,8X,'SIDE BEARING VERTICAL',11X,
     *2(F10.0,5X),2(5X,F10.0))
      WRITE(3,10071) CDBE,GDBE
10071 FORMAT(                        13X,'DAMPING TYPE',3X,'0-VISCOUS',3X,
     *2(I10,5X),2(5X,I10),/,13X,'DAMPING COEFF.',3X,'1-COULOMB',1X,
     *2(F10.0,5X),2(5X,F10.0))
      WRITE(3,10072) GKG,CDG
10072 FORMAT(                        8X,'SUSPENSION VERTICAL',13X,2(F10.0,5X)
     *,2(5X,F10.0),/,
     *13X,'DAMPING TYPE',3X,'0-VISCOUS',3X,2(I10,5X),2(5X,I10))
      WRITE(3,10073) GDG,GKS
10073 FORMAT(
     *13X,'DAMPING COEFF.',3X,'1-COULOMB',1X,2(F10.0,5X),2(5X,F10.0),/,
     *8X,'SUSPENSION LATERAL',14X,2(F10.0,5X),2(5X,F10.0))
      WRITE(3,10074) CDS,GDS
10074 FORMAT(
     *13X,'DAMPING TYPE',3X,'0-VISCOUS',3X,2(I10,5X),2(5X,I10),/,
     *13X,'DAMPING COEFF.',3X,'1-COULOMB',1X,2(F10.0,5X),2(5X,F10.0))
      WRITE(3,10075) GDSTK,STKTHR
10075 FORMAT(
     *8X,'STUCKI DAMPING COEFF.',11X,2(F10.0,5X),2(5X,F10.0),/,
     *13X,'PEAK LIMIT',1X,F10.0)
      CALL MRBL1A
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. K 05/03/79
      SUBROUTINE MRBL1A
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *           DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *           AA(113),FORBE(4),DAMSTK(4)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *            AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *            P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *            G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *            D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *             SFVER,THRESH
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *            GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *        POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *        DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *          ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      COMMON/ADD5/ADAR1
      WRITE(3,1008)GKW,CDW
1008  FORMAT(8X,'TRACK VERTICAL',18X,2(F10.0,5X),2(5X,F10.0),/,
     *13X,'DAMPING TYPE',3X,'0-VISCOUS',3X,2(I10,5X),2(5X,I10))
      WRITE(3,10081) GDW,GKWX
10081 FORMAT(
     *13X,'DAMPING COEFF.',3X,'1-COULOMB',1X,2(F10.0,5X),2(5X,F10.0),/,
     *8X,'TRACK LATERAL',19X,2(F10.0,5X),2(5X,F10.0))
      WRITE(3,10082) CDWX,GDWX
10082 FORMAT(
     *13X,'DAMPING TYPE',3X,'0-VISCOUS',3X,2(I10,5X),2(5X,I10),/,
     *13X,'DAMPING COEFF.',3X,'1-COULOMB',1X,2(F10.0,5X),2(5X,F10.0))
      WRITE(3,1009)T12,B12Z,B12X,T12X,T12Z
1009  FORMAT(6X,'STIFFNESSES BETWEEN CAR BODIES',/,8X,'TORSIONAL', 1X,
     *E12.5, 1X,'BENDING VERT.', 1X,E12.5, 1X,'BENDING LAT.', 1X,
     *E12.5,' PITCHING',1X,E12.5, 1X,'YAWING', 1X,E12.5)
      WRITE(3,1010) SFVER,SFLAT,COEFF
1010  FORMAT(6X,'STIFFNESSES OF SIDE FRAMES',4X,'VERTICAL',1X,E12.5,
     *5X,'LATERAL',2X,E12.5,/,6X,'COEFF. OF FRICTION AT GIB',14X,E12.5)
      WRITE(3,1011) DIS,VEL
1011  FORMAT(21X,'----------------------FRONT----------------------',5X,
     *'---------------------REAR---------------------',/,6X,'INITIAL DIS
     *PL.',5X,
     *   'LAT.',5X,'VERT.',6X,'ROLL',5X,'PITCH',7X,'YAW',7X,'LAT.',5X,'V
     *ERT.',6X,'ROLL',6X,'PITCH',5X,'YAW',/,
     *8X,'CAR BODIES',1X,5F10.4,1X,5F10.4,/,
     *8X,'BOLSTERS',3X,3F10.4,21X,3F10.4,/,
     *8X,'WHEELSETS',2X,3F10.4,21X,3F10.4,/,
     *6X,'INITIAL VELOCITY',3X,'LAT.',5X,'VERT.',5X,'ROLL',6X,'PITCH',7X,
     *,'YAW',6X,'LAT.',6X,'VERT.',5X,'ROLL',6X,'PITCH',7X,'YAW',/,
     *8X,'CAR BODIES',1X,5F10.4,1X,5F10.4,/,
```

```
     *8X,'BOLSTERS',3X,3F10.4,21X,3F10.4,/,
     *8X,'WHEELSETS',2X,3F10.4,21X,3F10.4)
      TN=FLOAT(NT)*DT
      WRITE(3,1012) V,DT,TN,T,DTMAX
1012  FORMAT(6X,'TRAIN SPEED:',F6.2,' FT/SEC,',2X,'TIME INCREMENT:',F7.5
     *,' SECS,',1X,'PRINT INCREMENT:',F6.2,' SECS,',/,6X,'START TIME: ',
     *F6.2,' SECS,',4X,'STOP TIME:',6X,F6.2,' SECS')
      PRINT 1017, ADAR1,THRESH
1017  FORMAT(/,' STUCKI DAMPER STROKE =',1X,F10.5,5X,' THRESH LEVEL=',
     .1X,F10.5)
      GO TO (1,2,3),IOPT
1     PRINT 1013
1013  FORMAT(    /,' * ABBREVIATED OUTPUT')
      GO TO 10
2     PRINT 1014
1014  FORMAT(    /,' * FULL OUTPUT')
      GO TO 10
3     PRINT 1015
1015  FORMAT(    /,' * FULL AND ABBREVIATED OUTPUT')
10    PRINT 1016
1016  FORMAT(1H1)
      RETURN
      END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE RUNG2(N,X,JT)
      COMMON/T1/Y(40),F(40),SAVEY(40),DTHALF
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      JT=JT+1
      GO TO (1,2,3),JT
    1 RETURN
2     DO 5 J=1,N
      SAVEY(J)=Y(J)
      Y(J)=Y(J)+DTHALF*F(J)
5     CONTINUE
      X=X+DTHALF
      RETURN
3     DO 10 J=1,N
      Y(J)=SAVEY(J)+DT*F(J)
10    CONTINUE
      X=X+DTHALF
      JT=0
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE MRBS22(P,JT)
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T1/Y(40),F(40),SAVEY(40),DTHALF
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON/T72/TEM2,TEM3,TEM4,TEM5,TEMPI,TEMPJ,TEMP,TEM6,TEM7,SINTH,
     C COSTH,PTEMP,THETA
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S         DATE  12,5,5
      DO 600 I=1,10
  600 DIS(I)=Y(I)
      DIS(12)=Y(11)
      DIS(13)=Y(12)
      DO 601  I=13,20
      J=I+2
  601 DIS(J)=Y(I)
      DO 700 I=21,30
      J=I-20
  700 VEL(J)=Y(I)
      VEL(12)=Y(31)
      VEL(13)=Y(32)
      DO 701 I=33,40
      J=I-18
  701 VEL(J)=Y(I)
      DIS(11)=DIS(1)-D1*DIS(5)-B1*DIS(3)
      DIS(14)=DIS(6)+D2*DIS(10)-B2*DIS(8)
      VEL(11)=VEL(1)-D1*VEL(5)-B1*VEL(3)
      VEL(14)=VEL(6)+D2*VEL(10)-B2*VEL(8)
      TEMP=OM*P+THETA
      X1=1.
      Z=1.
      IF(TEMP-THETA.LT.PIX2)X1=OM*P/PIX2
      IF(TEMP-THETA-PH2.LT.PIX2) Z=(OM*P-PH2)/PIX2
      GO TO (92,93),NRP
92    CONTINUE
      R1=   (SIN(TEMP))
      R2=   (SIN(TEMP-PH1))
      R3=   (SIN(TEMP-PH2))
      R4=   (SIN(TEMP-PH3))
C         RECTIFIED SINE
C     R1D=(ABS(R1)+ABS(SIN(TEMP-PH4)))*SHALF-PQ1
C     R2D=(ABS(R2)+ABS(SIN(TEMP-PH1-PH4)))*SHALF-PQ1
C     R3D=(ABS(R3)+ABS(SIN(TEMP-PH2-PH4)))*SHALF-PQ1
C     R4D=(ABS(R4)+ABS(SIN(TEMP-PH3-PH4)))*SHALF-PQ1
C         TRUE SINE
      R1D=(R1+    (SIN(TEMP-PH4)))*SHALF-PQ1
      R2D=(R2+    (SIN(TEMP-PH1-PH4)))*SHALF-PQ1
```

```
      R3D=(R3 +     (SIN(TEMP-PH2-PH4)))*SHALF-PQ1
      R4D=(R4 +    (SIN(TEMP-PH3-PH4)))*SHALF-PQ1
      R1D=R1D*X1
      R2D=R2D*X1
      R3D=R3D*Z
      R4D=R4D*Z
920   RD(1)=(R1D-R(1))/DTHALF
      RD(2)=(R2D-R(2))/DTHALF
      RD(3)=(R3D-R(3))/DTHALF
      RD(4)=(R4D-R(4))/DTHALF
      R(1)=R1D
      R(2)=R2D
      R(3)=R3D
      R(4)=R4D
      GO TO 51
      IF((OM*P-PH2).GT.0.) GO TO 51
      R(3)=0.
      R(4)=0.
      RD(3)=0.
      RD(4)=0.
   51 DO 54 I=1,4
      IF(POW(I).LT.POWMAX(I)) POWMAX(I)=POW(I)
      IF(POW(I)) 53,53,54
   53 R(I)=0.
      RD(I)=0.
   54 CONTINUE
93    RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE MRB2A2(P,NDJ,JT)
      DOUBLE PRECISION A
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON/T72/TEM2,TEM3,TEM4,TEM5,TEMPI,TEMPJ,TEMP,TEM6,TEM7,SINTH,
     C COSTH,PTEMP,THETA
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S        DATE  12,5,5
93    R11=TEMPJ
      IF((TEMP-PTEMP)    .GT.0.) R11=1.
      R31=ABS(TEMPJ*TEM4-TEMPI*TEM5)
      IF((TEMP-PH2).LT.0.) R31=1.
      IF((TEMP-PH2-PTEMP)    .GT.0.) R31=1.
      R12=TEMPJ*TEM2+TEMPI*TEM3
      IF((TEMP-PH4).LT.0.) R12=1.
      R32=TEMPJ*TEM6+TEMPI*TEM7
      IF((TEMP-PH2-PH4).LT.0.) R32=1.
      IF((TEMP-PH2-PH4-PTEMP)    .GT.0.) R32=1.
      R1= (R11+R12)*SQUART-SHALF
      R3= (R31+R32)*SQUART-SHALF
      R2=R1
      R4=R3
      RD(1)=(R1-R(1))/DT
      RD(2)=(R2-R(2))/DT
      RD(3)=(R3-R(3))/DT
      RD(4)=(R4-R(4))/DT
      R(1)=R1
      R(2)=R2
      R(3)=R3
      R(4)=R4
51    DO 54 I=1,4
      IF(POW(I))53,53,54
53    R(I)=0.
      RD(I)=0.
54    CONTINUE
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F.(NS)
SYM3 REV.G
:F
SYM3 REV.G
:F
SYM3 REV.G
:F
SYM3 REV.G
:F
SYM3 REV.G
:F
SYM3 REV.G
:F
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. K 04/30/79
      SUBROUTINE MRBS32
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T4/S1,S2,S3,S4,ZB1,ZB2,ZB3,ZB4,CW1,CW2,CW3,CW4
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *         AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *         P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *         G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *         D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *         GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S         DATE  11,5,26
      TEMP=DIS(12)-DIS(2)-DIS(4)*D1
      TEMP1=DIS(3)-DIS(13)
      POP(1)=TEMP-P1*TEMP1
      POP(2)=TEMP+P2*TEMP1
      POBE(1)=TEMP-BE1*TEMP1-ZB1
      POBE(2)=TEMP+BE2*TEMP1-ZB2
      TEMP=DIS(15)-DIS(7)+DIS(9)*D2
      TEMP1=DIS(8)-DIS(16)
      POP(3)=TEMP-P3*TEMP1
      POP(4)=TEMP+P4*TEMP1
      POBE(3)=TEMP-BE3*TEMP1-ZB3
      POBE(4)=TEMP+BE4*TEMP1-ZB4
      POS(1)=DIS(11)-DIS(17)-ZS1*DIS(19)
      POS(2)=POS(1)
      POS(3)=DIS(14)-DIS(20)-ZS3*DIS(22)
      POS(4)=POS(3)
      TEMP=DIS(18)-DIS(12)
      TEMP1=DIS(13)-DIS(19)
      POG(1)=TEMP-G1*TEMP1
      POG(2)=TEMP+G2*TEMP1
      TEMP=DIS(21)-DIS(15)
      TEMP1=DIS(16)-DIS(22)
      POG(3)=TEMP-G3*TEMP1
      POG(4)=TEMP+G4*TEMP1
      POW(1)=R(1)-DIS(18)-W1*DIS(19)
      POW(2)=R(2)-DIS(18)+W2*DIS(19)
      POW(3)=R(3)-DIS(21)-W3*DIS(22)
      POW(4)=R(4)-DIS(21)+W4*DIS(22)
      POWX(1)=-DIS(17)+C1*DIS(19)-CW1
      POWX(2)=DIS(17)-C2*DIS(19)-CW2
      POWX(3)=-DIS(20)+C3*DIS(22)-CW3
      POWX(4)=DIS(20)-C4*DIS(22)-CW4
      TEMP=VEL(12)-VEL(2)-VEL(4)*D1
      TEMP1=VEL(3)-VEL(13)
      VELBE(1)= TEMP-BE1*TEMP1
      VELBE(2)=TEMP+BE2*TEMP1
      TEMP=VEL(15)-VEL(7)+VEL(9)*D2
      TEMP1=VEL(8)-VEL(16)
      VELBE(3)=TEMP-BE3*TEMP1
      VELBE(4)=TEMP+BE4*TEMP1
```

```
      VELS(1)=VEL(11)-VEL(17)-ZS1*VEL(19)
      VELS(2)=VELS(1)
      VELS(3)=VEL(14)-VEL(20)-ZS3*VEL(22)
      VELS(4)=VELS(3)
      TEMP=VEL(18)-VEL(12)
      TEMP1=VEL(13)-VEL(19)
      VELG(1)=TEMP-G1*TEMP1
      VELG(2)=TEMP+G2*TEMP1
      TEMP=VEL(21)-VEL(15)
      TEMP1=VEL(16)-VEL(22)
      VELG(3)=TEMP-G3*TEMP1
      VELG(4)=TEMP+G4*TEMP1
      DO 10 I=1,4
      VELSTK(I)=VELG(I)
10    CONTINUE
      VELW(1)=-VEL(18)-W1*VEL(19)+RD(1)
      VELW(2)=-VEL(18)+W2*VEL(19)+RD(2)
      VELW(3)=-VEL(21)-W3*VEL(22)+RD(3)
      VELW(4)=-VEL(21)+W4*VEL(22)+RD(4)
      VELWX(1)=-VEL(17)+C1*VEL(19)
      VELWX(2)=VEL(17)-C2*VEL(19)
      VELWX(3)=-VEL(20)+C3*VEL(22)
      VELWX(4)=VEL(20)-C4*VEL(22)
      ZS1=S1-POG(1)
      ZS2=S2-POG(2)
      ZS3=S3-POG(3)
      ZS4=S4-POG(4)
      REA1=AM3*ACC(11)+POS(1)*AKS(1)+POS(2)*AKS(2)
      RETURN
      END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. K 04/30/79
      SUBROUTINE SPCON
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *            SFVER,THRESH
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
C
C         SET STIFFNESS PARAMETERS FROM CORRESPONDING STIFFNESS INPUTS AFTER
C              CONSIDERING POSITIONS
C
      DO  600 I=1,4
C
C         SET CENTERPLATE STIFFNESS
C
      IF (POP(I)) 10,20,20
   10 AKP(I)=0.
      GO TO 100
   20 AKP(I)=GKP(I)
C
C         SET SIDE BEARING STIFFNESS
C
100   IF (POBE(I)) 110,120,120
  110 AKBE(I)=0.
      GO TO 200
  120 AKBE(I)=GKBE(I)
C
C         SET VERTICAL SUSPENSION STIFFNESS
C
200   RL=POG(I)
      IF (RL-POGC) 210,220,220
  210 AKG(I)=GKG(I)
      GO TO 300
  220 AKG(I)=(GKG(I)*POGC+(RL-POGC)*SFVER)/RL
C
C         SET LATERAL SUSPENSION STIFFNESS
C
300   RL=ABS(POS(I))
      IF (RL-XSC(I)) 310,320,320
  310 AKS(I)=GKS(I)
      GO TO 400
  320 AKS(I)=(GKS(I)*XSC(I)+(RL-XSC(I))*SFLAT)/RL
C
C         SET VERTICAL TRACK STIFFNESS
C
400   IF (POW(I)) 410,420,420
  410 AKW(I)=0.
      GO TO 500
  420 AKW(I)=GKW(I)
C
C         SET LATERAL TRACK STIFFNESS
C
500   IF (POWX(I)) 510,520,520
  510 AKWX(I)=0.
      GO TO 600
  520 AKWX(I)=GKWX(I)
  600 CONTINUE
```

```
RDS-500 FORTRAN4 REV. G 04/30/79
      SUBROUTINE DAM2
      INTEGER CDBE,CDG,CDS,CDW,CDWX
      DOUBLE PRECISION GKP,GKBE,GKG,GKS,GKW,GKWX,SFLAT,SFVER
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON /ADD/XSC(4),POGC,COEFF,COTEMP
      COMMON /BB1/GKP(4),GKBE(4),GKS(4),GKG(4),GKW(4),GKWX(4),SFLAT,
     *            SFVER,THRESH
      COMMON /PR2/CDBE(4),CDG(4),CDS(4),CDW(4),CDWX(4),GDBE(4),GDS(4),
     *          GDG(4),GDW(4),GDWX(4),REA1,GDSTK(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      COMMON/ADD5/ADAR1
      DO 700 I=1,4
C
C         SET DAMPING PARAMETERS FOR BEARING
C
      IF(POBE(I).GE.0.) GO TO 120
  110 DBE(I)=0.
      GO TO 200
  120 JJ=CDBE(I)+1
      GO TO (160,130,130),JJ
C
C         COULOMB DAMPING
C
  130 IF (VELBE(I) .GT. 0.) GO TO 140
      VELBE(I)=-1.
      GO TO 150
  140 VELBE(I)=1.
  150 GO TO (160,160,170),JJ
C
C         VISCOUS DAMPING + COULOMB DAMPING
C
  160 DBE(I)=GDBE(I)
      GO TO 200
C
C         MYSTERIOUS THIRD  TYPE DAMPING
C
  170 DBE(I)=GDBE(I)*ABS(REA1)
C
C         SETS DAMPING PARAMETERS FOR SPRING GROUPS - VERTICAL
C
200    JJ=CDG(I)+1
      GO TO (260,230),JJ
C
C         COULOMB DAMPING
C
230   HYPO=SQRT(VELS(I)*VELS(I)+VELG(I)*VELG(I))
      IF (HYPO) 290,280,290
  290 CONTINUE
      RFACTG=1.
      IF(ABS(VELG(I)).LT. THRESH) RFACTG=ABS(VELG(I))/THRESH
      RFACTS=1.
      IF(ABS(VELS(I)).LT. THRESH) RFACTS=ABS(VELS(I))/THRESH
      TEMP=GDG(I)/HYPO
C OLD DG(I)=GDG(I)*(ABS(VELG(I))/HYPO)
      DG(I)=TEMP*ABS(VELG(I))*RFACTG
C OLD DS(I)=GDG(I)*(ABS(VELS(I))/HYPO)
```

```
      DS(I)=TEMP*ABS(VELS(I))*RFACTS
      IF (VELG(I) .GT. 0.) GO TO 240
      VELG(I)=0.0
C
      GO TO 250
  240 VELG(I)=1.
  250 RL=ABS(POS(I))
      TEST=RL-XSC(I)
      IF(TEST.LT.0.) GO TO 300
C0270 DG(I)=DG(I)+COEFF*TEST*SFLAT
  270 DG(I)=DG(I)+(TEST*COTEMP)*RFACTG
      GO TO 300
C
C         VISCOUS DAMPING
C
  260 DG(I)=GDG(I)
      IF(CDG(I).EQ.0) CDS(I)=0
      GO TO 300
C
C         COULOMB DAMPING  HYPO =0
C
  280 DG(I)=0.
      DS(I)=0.
C
C         SET DAMPING PARAMETERS FOR SPRING GROUP - LATERAL
C
300   JJ=CDS(I)+1
      GO TO (360,330),JJ
C
C         COULOMB DAMPING
C
  330 IF (VELS(I) .GT. 0.) GO TO 340
      VELS(I)=-1.
      GO TO 400
  340 VELS(I)=1.
      GO TO 400
C
C         VISCOUS DAMPING
C
  360 DS(I)=GDS(I)
C
C         SET DAMPING PARAMETERS FOR TRACK - VERTICAL
C
400   IF (POWX(I).GE.0.) GO TO 420
  410 DW(I)=0.
      GO TO 500
  420 JJ=CDW(I)+1
      GO TO (460,430,430),JJ
C
C         COULOMB DAMPING
C
  430 IF (VELW(I) .GT. 0.) GO TO 440
      VELW(I)=-1.
      GO TO 450
  440 VELW(I)=1.
  450 GO TO (460,460,470),JJ
  460 DW(I)=GDW(I)
      GO TO 500
C
C         MYSTERIOUS THIRD TYPE  DAMPING
```

```
C
C
C         VISCOUS DAMPING + COULOMB DAMPING
C
  470 DW(I)=AKWX(I)*POWX(I)*GDW(I)
C
C         SET DAMPING PARAMETERS FOR TRACK - LATERAL
C
500   IF (POW(I).GT.0.) GO TO 520
  510 DWX(I)=0.
      GO TO 600
  520 JJ=CDWX(I)+1
      GO TO (560,530,530),JJ
C
C         COULOMB DAMPING
C
  530 IF (VELWX(I) .GT. 0.) GO TO 540
      VELWX(I)=-1.
      GO TO 550
  540 VELWX(I)=1.
  550 GO TO (560,560,570),JJ
C
C         VISCOUS DAMPING + COULOMB DAMPING
C
  560 DWX(I)=GDWX(I)
      GO TO 600
C
C         MYSTERIOUS THIRD FORM  DAMPING
C
  570 DWX(I)=AKW(I)*POW(I)*GDWX(I)
C
C
C         SET DAMPING PARAMETERS FOR STUCKI DAMPING - SPRING GROUPS
C                   VERTICAL AND ROLL
600   IF(VELSTK(I).GT.0.) GO TO 620
      DSTK(I)=0.
      GO TO 700
620   DSTK(I)=GDSTK(I)
      ADAR=POGC-ADAR1
      IF(POG(I).LT.ADAR) DSTK(I)=0.
      IF(DSTK(I)*VELSTK(I).LT.STKTHR) GO TO 700
      DSTK(I)=STKTHR/VELSTK(I)
700   CONTINUE
      RETURN
      END
NO ERRORS
SYM3 REV.H
```

```
RDS-500 FORTRAN4 REV. K 04/30/79
       SUBROUTINE ACCEL
       CALL ACCS1
       CALL ACCS2
       CALL ACCS3
       CALL ACCS4
       CALL ACCS5
       RETURN
       END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-503 FORTRAN4 REV. F 04/29/79
      SUBROUTINE ACCS1
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T2/RR(4),RDD(4),APOP(4),APOG(4),APOW(4),APOWX(4),APOS(4),
     * DVELBE(4),DVELG(4),DVELW(4),DVELWX(4),DVELS(4),DD(20),EE(20),
     *          AA(113),APOBE(4),DVELSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON/AA2/FS(4),GS(4)
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S        DATE  11,5,26
      FBEN=B12Z*(DIS(2)-DIS(7)-D1PI*DIS(4)-D2PI*DIS(9))
      DO 10 I=1,4
      DVELBE(I)=DBE(I)*VELBE(I)
      APOBE(I)=AKBE(I)*POBE(I)
      APOP(I)=AKP(I)*POP(I)
      DVELG(I)=DG(I)*VELG(I)
      APOG(I)=AKG(I)*POG(I)
      DVELS(I)=DS(I)*VELS(I)
      APOS(I)=AKS(I)*POS(I)
      APOWX(I)=AKWX(I)*POWX(I)
      DVELWX(I)=DWX(I)*VELWX(I)
      APOW(I)=AKW(I)*POW(I)
      DVELW(I)=DW(I)*VELW(I)
      DVELSTK(I)=DSTK(I)*VELSTK(I)
10    CONTINUE
      ACC(2)=(-AM1*G+DVELBE(2)+DVELBE(1)+APOBE(2)
     *        +APOBE(1)+APOP(2)+APOP(1)-FBEN)/AM1
      ACC(7)=(-AM2*G+DVELBE(4)+DVELBE(3)+APOBE(4)+
     *       APOBE(3)+APOP(4)+APOP(3)+FBEN)/AM2
C        PARTIAL COMPUTATION OF ACC(12),(13),(15),(16)
      ACC(12)=-AM3*G-DVELBE(2)-DVELBE(1)+APOG(2)+APOG(1)
     *                -APOBE(2)- APOBE(1)- APOP(2)- APOP(1)
     *               +DVELSTK(1)+DVELSTK(2)
      ACC(13)=BE2*DVELBE(2)-BE1*DVELBE(1)-G2*APOG(2)+G1*APOG(1)
     *       +BE2*APOBE(2) -BE1*APOBE(1)+P2*APOP(2)-P1*APOP(1)
     *       -G2*DVELSTK(2)+G1*DVELSTK(1)
      ACC(15)=-AM4*G-DVELBE(4)-DVELBE(3)+APOG(4)+APOG(3)
     *                -APOBE(4)-APOBE(3)-APOP(4)-APOP(3)
     *               +DVELSTK(3)+DVELSTK(4)
      ACC(16)=BE4*DVELBE(4)-BE3*DVELBE(3)-G4*APOG(4)+G3*APOG(3)
     *             +BE4*APOBE(4)-BE3*APOBE(3)+P4*APOP(4)-P3*APOP(3)
     *       -G4*DVELSTK(4)+G3*DVELSTK(3)
      GS(1)=DVELG(2)+DVELG(1)
      GS(2)=-G2*DVELG(2)+G1*DVELG(1)
      GS(3)=DVELG(4)+DVELG(3)
      GS(4)=-G4*DVELG(4)+G3*DVELG(3)
30    ACC(12)=(       +ACC(12)+GS(1))/AM3
40    ACC(13)=(ACC(13)+GS(2))/AIY3
```

```
50     ACC(15)=(        +ACC(15)+GS(3))/AM4
60     ACC(16)=(ACC(16)+GS(4))/AIY4
       RETURN
       END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE ACCS2
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T2/RR(4),RDD(4),APOP(4),APOG(4),APOW(4),APOWX(4),APOS(4),
     * DVELBE(4),DVELG(4),DVELW(4),DVELWX(4),DVELS(4),DD(20),EE(20),
     *          AA(113),APOBE(4),DVELSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T8/TEMP1(10),TEMP2(10),IFLAG
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S        DATE  11,5,26
      ACC(17)=(DVELS(2)+DVELS(1)+APOS(2)+APOS(1) +
     *       APOWX(1)-APOWX(2)+DVELWX(1)-
     *       DVELWX(2))/AM5
      ACC(20)=(DVELS(4)+DVELS(3)+APOS(4)+APOS(3)+
     *       APOWX(3)-APOWX(4)+DVELWX(3)-
     *       DVELWX(4))/AM6
      ACC(18)=(APOW(2)+APOW(1)-DVELG(2)-DVELG(1)-
     *       DVELSTK(2)-DVELSTK(1)-
     *       APOG(2)-APOG(1)-AM5*G+DVELW(1)+
     *       DVELW(2))/AM5
      ACC(21)=(APOW(4)+APOW(3)-DVELG(4)-DVELG(3)-
     *       DVELSTK(4)-DVELSTK(3)-
     *       APOG(4)-APOG(3)-AM6*G+DVELW(3)+
     *       DVELW(4))/AM6
      ACC(19)=(G2*DVELG(2)-G1*DVELG(1)+G2*APOG(2)-
     *       G1*APOG(1)+ZS2*APOS(2)+ZS1*APOS(1)
     *       +G2*DVELSTK(2)-G1*DVELSTK(1)
     *       +ZS1*DVELS(1)+ZS2*DVELS(2)+W1*APOW(1)-
     *       W2*APOW(2)+W1*DVELW(1)-W2*DVELW(2)
     *       -C1*APOWX(1)+C2*APOWX(2)-C1*DVELWX(1)+
     *       C2*DVELWX(2))/AIY5
      ACC(22)=(G4*DVELG(4)-G3*DVELG(3)+G4*APOG(4)-
     *       G3*APOG(3)+ZS4*APOS(4)+ZS3*APOS(3)
     *       +G4*DVELSTK(4)-G3*DVELSTK(3)
     *      +ZS3*DVELS(3)+ZS4*DVELS(4)+W3*APOW(3)-
     *       W4*APOW(4)+W3*DVELW(3)-W4*DVELW(4)
     *       -C3*APOWX(3)+C4*APOWX(4)-C3*DVELWX(3)+
     *       C4*DVELWX(4))/AIY6
      DO 100 I=1,10
      TEMP1(I)=DIS(I)
      TEMP2(I)=VEL(I)
      IF (ABS(DIS(I)) .LT. 1.0E-05) DIS(I)=0.
      IF (ABS(VEL(I)) .LT. 1.0E-05) VEL(I)=0.
  100 CONTINUE
      DO 105 I=1,5
      DO 105 J=1,5
      A(J,I)=0.D0
105   CONTINUE
```

```
110    A(1,1)=AM1+AM3
       A(1,2)=-AM3*B1
       A(1,3)=0.
       A(1,4)=-AM3*D1
       A(1,5)=-DVELS(2)-DVELS(1)-APOS(2)-APOS(1)
      *        -B12X*(DIS(1)-DIS(6))-AM3*(D1*DIS(5)*VEL(5)*VEL(5)
      *        +B1*DIS(3)*VEL(3)*VEL(3))
       A(2,1)=A(1,2)
       A(2,2)=AIY1-A(1,2)*B1
       A(2,3)=(AIX1-AIY1)*DIS(5)
       A(2,4)=AM3*D1*B1
       RETURN
       END
NO ERRORS
SYM3 REV.6
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE ACCS3
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T2/RR(4),RDD(4),APOP(4),APOG(4),APOW(4),APOWX(4),APOS(4),
     * DVELBE(4),DVELG(4),DVELW(4),DVELWX(4),DVELS(4),DD(20),EE(20),
     *          AA(113),APOBE(4),DVELSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S         DATE  11,5,26
      A(2,5)=BE1*DVELBE(1)-BE2*DVELBE(2)-D12*(VEL(3)-VEL(8))
     *       -BE2*APOBE(2)+BE1*APOBE(1)-
     *       P2*APOP(2)+P1*APOP(1)-T12*(DIS(3)-DIS(8))-
     *       AIX1*(VEL(4)*VEL(5)-VEL(4)*VEL(3)*DIS(5)*DIS(3)-VEL(4)*
     *       VEL(5)*DIS(5)*DIS(5)+2.*DIS(5)*VEL(3)*VEL(5))
     *-AIY1*(-2.*DIS(5)*VEL(5)*VEL(3)+VEL(5)*VEL(4)*DIS(5)*DIS(5)-VEL(4)
     *      *VEL(5)+DIS(5)*DIS(3)*VEL(4)*VEL(3))+B1*DVELS(2)+
     *      B1*(DVELS(1)+APOS(2)+APOS(1))
     *      -AIX1*(VEL(4)*VEL(4)*DIS(3)+VEL(4)*VEL(3)*DIS(3)*DIS(5))
      A(2,5)=A(2,5)-AIY1*(-VEL(3)*VEL(4)*DIS(3)*DIS(5)+VEL(4)*VEL(4)*
     *      DIS(3)*DIS(5)*DIS(5))+AIZ1*(VEL(4)*VEL(4)*DIS(3)+VEL(4)*
     *VEL(5))+AM3*B1*(D1*DIS(5)*VEL(5)*VEL(5)+B1*DIS(3)*VEL(3)*VEL(3))
      A(3,1)=0.
      A(3,2)=(AIX1-AIY1)*DIS(5)
      A(3,3)=AIX1+AIZ1*DIS(3)*DIS(3)+AIY1*DIS(5)*DIS(5)
      A(3,4)=AIZ1*DIS(3)
      A(3,5)=D1*(DVELBE(2)+DVELBE(1)+APOBE(2)+
     *      APOBE(1)+APOP(2)+APOP(1))-T12X*(DIS(4)-DIS(9))
     *       -AIX1*(-2.*VEL(4)*VEL(3)*DIS(3)-2.*VEL(4)*VEL(5)*DIS(5)
     *       +VEL(3)*VEL(5)-VEL(3)*VEL(5)*DIS(5)*DIS(5)-DIS(5)*DIS(3)*
     *       VEL(3)*VEL(3))
     *       +AIY1*(VEL(3)*VEL(5)-VEL(3)*VEL(5)*DIS(5)*DIS(5)-DIS(5)*
     *      DIS(3)*VEL(3)*VEL(3)
     *                  -2.*VEL(4)*DIS(5)*VEL(5)+2.*VEL(4)*VEL(3)*DIS(3)
```

```
*       *DIS(5)*DIS(5))
*       -AIZ1*(2.*VEL(4)*DIS(3)*VEL(3)+VEL(5)*VEL(3))  +  D1PI*FBEN
 A(4,1)=A(1,4)
 A(4,2)=-B1*A(1,4)
 A(4,3)=AIZ1*DIS(3)
 A(4,4)=AIZ1-A(4,1)*D1
 A(4,5)=D1*(DVELS(2)+DVELS(1)+APOS(2)+
*           APOS(1))-AIZ1*VEL(4)*VEL(3)
*       -T12Z*(DIS(5)-DIS(10))+AIX1*(-VEL(4)*VEL(4)*DIS(5)-VEL(4)
*       *VEL(3)*DIS(5)*DIS(5)+VEL(3)*VEL(4)+VEL(3)*VEL(3)*DIS(5))
*       +AIY1*(-VEL(3)*VEL(3)*DIS(5)-VEL(3)*VEL(4)+VEL(4)*VEL(4)*
*      DIS(5)+VEL(4)*VEL(3)*DIS(5)*DIS(5))
*       +AM3*D1*(D1*DIS(5)*VEL(5)*VEL(5)+B1*DIS(3)*VEL(3)*VEL(3))
 CALL GAUSS (A,X,4)
 ACC(1)=X(1)
```

```
      ACC(3)=X(2)
      ACC(4)=X(3)
      ACC(5)=X(4)
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE ACCS4
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T2/RR(4),RDD(4),APOP(4),APOG(4),APOW(4),APOWX(4),APOS(4),
     * DVELBE(4),DVELG(4),DVELW(4),DVELWX(4),DVELS(4),DD(20),EE(20),
     *          AA(113),APOBE(4),DVELSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *          AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *          P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *          G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *          D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S         DATE  11,5,26
      DO 105 I=1,5
      DO 105 J=1,5
      A(J,I)=0.D0
105   CONTINUE
      A(1,1)=AM2+AM4
      A(1,2)=-AM4*B2
      A(1,3)=0.
      A(1,4)=AM4*D2
      A(1,5)=-DVELS(4)-DVELS(3)-APOS(4)-APOS(3)+
     *       B12X*(DIS(1)-DIS(6))+AM4*(D2*DIS(10)*VEL(10)*VEL(10)
     *      -B2*DIS(8)*VEL(8)*VEL(8))
      A(2,1)=A(1,2)
      A(2,2)=AIY2+AM4*B2*B2
      A(2,3)=(AIX2-AIY2)*DIS(10)
      A(2,4)=A(1,2)*D2
      A(2,5)=-BE4*DVELBE(4)+BE3*DVELBE(3)+D12*(VEL(3)-VEL(8))
     *        -BE4*APOBE(4)+BE3*APOBE(3)-
     *       P4*APOP(4)+P3*APOP(3)+T12*(DIS(3)-DIS(8))-
     *       AIX2*(VEL(9)*VEL(10)-VEL(9)*VEL(8)*DIS(10)*DIS(8)-VEL(9)
     *       *DIS(10)
     *       *VEL(10)*DIS(10)    +2.*DIS(10)*VEL(8)*VEL(10))-AIY2*(-2.*
     *       DIS(10)*VEL(10)*VEL(8)+VEL(10)*VEL(9)*DIS(10)*DIS(10)
     *       -VEL(9)*
     *       VEL(10)+DIS(10)*DIS(8)*VEL(9)*VEL(8))+B2*(DVELS(4)+
     *          DVELS(3)+APOS(4)+APOS(3))-AIX2*(VEL(9)
     *             *VEL(9)    *DIS(8)+VEL(9)*VEL(8)*DIS(8)*DIS(10))
      A(2,5)=A(2,5)-AIY2*(-VEL(8)*VEL(9)*DIS(8)*DIS(10)+VEL(9)*VEL(9)
     * *DIS(8)*DIS(10)*
     *       DIS(10))+AIZ2*(VEL(9)*(VEL(9)*DIS(8)+VEL(10)))+
     *       A(1,2)*(D2*DIS(10)*VEL(10)*VEL(10)-B2*DIS(8)*VEL(8)*VEL(8))
      RETURN
      END
NO ERRORS
SYM3 REV.G
 :F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE ACCS5
      DOUBLE PRECISION A
      DOUBLE PRECISION AIX1,AIX2,AIZ1,AIZ2,AIY1,AIY2,AIY3,AIY4,AIY5,T12,
     C AIY6,B12Z,B12X,T12X,T12Z
      COMMON/T2/RR(4),RDD(4),APOP(4),APOG(4),APOW(4),APOWX(4),APOS(4),
     * DVELBE(4),DVELG(4),DVELW(4),DVELWX(4),DVELS(4),DD(20),EE(20),
     *          AA(113),APOBE(4),DVELSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T8/TEMP1(10),TEMP2(10),IFLAG
      COMMON /AA/DIS(22),VEL(22),ACC(22),AIX1,AIX2,AIY1,AIY2,AIZ1,AIZ2,
     *           AIY3,AIY4,AIY5,AIY6,AM1,AM2,AM3,AM4,AM5,AM6,
     *           P1,P2,P3,P4,BE1,BE2,BE3,BE4,ZS1,ZS2,ZS3,ZS4,
     *           G1,G2,G3,G4,W1,W2,W3,W4,B1,B2,D1,D2,T12,B12X,B12Z,
     *           D12,G,T12X,T12Z,C1,C2,C3,C4,PP,FBEN,NRP
      COMMON/AA1/D1PI,D2PI,FVER1,FVER2,FVER3,FVER4,FVER5,FVER6,FLAT1,
     * FLAT2,FLAT3,FLAT4,FLAT5,FLAT6
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S       DATE  11,5,26
      A(3,1)=0.
      A(3,2)=(AIX2-AIY2)*DIS(10)
      A(3,3)=AIX2+AIZ2*DIS(8)*DIS(8)+AIY2*DIS(10)*DIS(10)
      A(3,4)=AIZ2*DIS(8)
      A(3,5)=-D2*(DVELBE(4)+DVELBE(3)+APOBE(4)+APOBE(3)+APOP(4)+APOP(3))
     *       -T12X*(DIS(9)-DIS(4))
     *       -AIX2*(-2.*VEL(9)*VEL(8)*DIS(8)-2.*VEL(9)*VEL(10)*DIS(10)+
     *       VEL(8)*VEL(10)-VEL(8)*VEL(10)*DIS(10)*DIS(10)-DIS(10)*
     *       DIS(8)*VEL(8)*VEL(8))
     *       +AIY2*(VEL(8)*VEL(10)-VEL(8)*VEL(10)*DIS(10)*DIS(10)
     *       -DIS(10)*DIS(8)*VEL(8)
     *          *VEL(8)    -2.*VEL(9)*VEL(10)*DIS(10)+2.*VEL(9)*
     *       VEL(8)*DIS(8)*DIS(10)*DIS(10))
     *       -AIZ2*(2.*VEL(9)*VEL(8)*DIS(8)+VEL(10)*VEL(8)) + D2PI*FBEN
      A(4,1)=A(1,4)
      A(4,2)=A(2,4)
      A(4,3)=AIZ2*DIS(8)
      A(4,4)=AIZ2+A(4,1)*D2
      A(4,5)=-D2*(DVELS(4)+DVELS(3)+APOS(4)+
     *          APOS(3))-AIZ2*VEL(9)*VEL(8)
     *       -T12Z*(DIS(10)-DIS(5))+AIX2*(-VEL(9)*VEL(9)*DIS(10)-VEL(9)*
     *       VEL(8)*
     *      DIS(10)*DIS(10)    +VEL(8)*VEL(9)+VEL(8)*VEL(8)*DIS(10))+AIY2
     *    *(-VEL(8)*VEL(8)    *DIS(10)-VEL(8)*VEL(9)+VEL(9)*VEL(9)*
     *       DIS(10)
     *       +VEL(9)*VEL(8)*DIS(10)*DIS(10))
     *    -AM4*D2*(-D2*DIS(10)*VEL(10)*VEL(10)+B2*DIS(8)*VEL(8)*VEL(8))
      CALL GAUSS (A,X,4)
      ACC(6)=X(1)
      ACC(8)=X(2)
      ACC(9)=X(3)
      ACC(10)=X(4)
190   DO 200 I=1,10
      DIS(I)=TEMP1(I)
      VEL(I)=TEMP2(I)
  200 CONTINUE
      RETURN
      END
```

```
RDS-500 FORTRAN4 REV. K 05/03/79
       SUBROUTINE MRBS4
       DOUBLE PRECISION A
       COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
      *           DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
      *           AA(113),FORBE(4),DAMSTK(4)
       COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
C OLD COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,Q,OM
       COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
       COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
      *        POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
      *        DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
      *         ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
S         DATE  11,5,26
       DO 400 I=1,4
       RR(I)=R(I)*12.
       RDD(I)=RD(I)*12.
       FORBE(I)=FORBE(I)+DAMBE(I)
       FORW(I)=FORW(I)+DAMW(I)
       FORWX(I)=FORWX(I)+DAMWX(I)
       FORS(I)=FORS(I)+DAMS(I)
       POG(I)=POG(I)*12.
   400 CONTINUE
       RETURN
       END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. K 05/03/79
      SUBROUTINE MRBS5
      DOUBLE PRECISION A
      COMMON/T1/Y(40),F(40),SAVEY(40),DTHALF
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      COMMON/T3/R(4),RD(4),A(5,5),X(4),CC(20)
      COMMON/T5/V,AL,S,D,B,SHALF,SQUART,PI,PIHALF,PIX2,SLOPE,YNTRCP,BL2
C OLD COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,Q,OM
      COMMON/T7/PH1,PH2,PH3,PH4,PQ1,PQ2,PQ3,PQ4,T,OM
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *       POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *       DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *        ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      DATA DEG/ 57.29578/
      CC(1)=Y(1)*12.
      CC(2)=Y(2)*12.
      CC(3)=Y(3)*DEG
      CC(4)=Y(4)*DEG
      CC(5)=Y(5)*DEG
      CC(6)=Y(6)*12.
      CC(7)=Y(7)*12.
      CC(8)=Y(8)*DEG
      CC(9)=Y(9)*DEG
      CC(10)=Y(10)*DEG
      CC(11)=Y(11)*12.
      CC(12)=Y(12)*DEG
      CC(13)=Y(13)*12.
      CC(14)=Y(14)*DEG
      CC(15)=Y(15)*12.
      CC(16)=Y(16)*12.
      CC(17)=Y(17)*DEG
      CC(18)=Y(18)*12.
      CC(19)=Y(19)*12.
      CC(20)=Y(20)*DEG
      DD(1)=Y(21)*12.
      DD(2)=Y(22)*12.
      DD(3)=Y(23)*DEG
      DD(4)=Y(24)*DEG
      DD(5)=Y(25)*DEG
      DD(6)=Y(26)*12.
      DD(7)=Y(27)*12.
      DD(8)=Y(28)*DEG
      DD(9)=Y(29)*DEG
      DD(10)=Y(30)*DEG
      DD(11)=Y(31)*12.
      DD(12)=Y(32)*DEG
      DD(13)=Y(33)*12.
      DD(14)=Y(34)*DEG
      DD(15)=Y(35)*12.
      DD(16)=Y(36)*12.
      DD(17)=Y(37)*DEG
      DD(18)=Y(38)*12.
      DD(19)=Y(39)*12.
      DD(20)=Y(40)*DEG
      EE(1)=F(21)/32.175
      EE(2)=F(22)/32.175
      EE(3)=F(23)
      EE(4)=F(24)
```

```
      EE(5)=F(25)
      EE(6)=F(26)*12.
      EE(7)=F(27)*12.
      EE(8)=F(28)*DEG
      EE(9)=F(29)*DEG
      EE(10)=F(30)*DEG
      EE(11)=F(31)*12.
      EE(12)=F(32)*DEG
      EE(13)=F(33)*12.
      EE(14)=F(34)*DEG
      EE(15)=F(35)*12.
      EE(16)=F(36)*12.
      EE(17)=F(37)*DEG
      EE(18)=F(38)*12.
      EE(19)=F(39)*12.
      EE(20)=F(40)*DEG
      C(1)=(Y(11)-Y(2)+3.96*(Y(12)-Y(3)))*12.
      C(2)=(Y(11)-Y(2)+3.96*(Y(3)-Y(12)))*12.
      C(3)=(Y(13)-Y(7)+3.96*(Y(14)-Y(8)))*12.
      C(4)=(Y(13)-Y(7)+3.96*(Y(8)-Y(14)))*12.
8     FORMAT(8E15.8)
CO    WRITE(10,8)(CC(I),I=1,20),(DD(I),I=1,20),(EE(I),I=1,20),T
      WRITE(9,8) CC,DD,EE,RR,RDD,FORP,FORBE,FORW,FORWX,FORS,DAMG,POG,
     *  FORG,POW,DAMS,C,T
      RETURN
      END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE MEND
      COMMON/T6/DT,DTMAX,NT,KODE,ID(40),IOPT
      COMMON/M/VELBE(4),VELS(4),VELG(4),POP(4),POBE(4),POS(4),POG(4),
     *        POW(4),AKP(4),AKBE(4),AKS(4),AKG(4),AKW(4),DBE(4),DG(4),
     *        DS(4),DW(4),POWX(4),AKWX(4),VELW(4),VELWX(4),DWX(4)
     *         ,VELSTK(4),DSTK(4),STKTHR,POWMAX(4),C(4)
      DO 50 I=1,4
      POWMAX(I)=ABS(POWMAX(I))*12.
50    CONTINUE
      WRITE(3,100) POWMAX
100   FORMAT('1MAX WHEELLIFT:    L. FRONT ',F4.1,', R. FRONT ',F4.1,', L.
     * REAR ',F4.1,', R. REAR ',F4.1)
  200 ENDFILE 9
      ENDFILE 10
      IF(IOPT.EQ.2) GO TO 210
      CALL MRBL4
      IF(IOPT.EQ.1) GO TO 220
210   CALL MRBL2
      CALL MRBL3
220   STOP
      RETURN
      END
NO ERRORS
SYM3 REV.G
:F
```

```
RDS-500 FORTRAN4 REV. K 05/03/79
      SUBROUTINE MRBL4
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      REWIND 9
      WRITE(3,100)
100   FORMAT(1H1,8X,'---------FRONT CAR BODY------  ---SPRING DEFLECTIONS
     *---  ------------------LOAD-------------------  ------WHEEL LIFT--
     *-----',/,
     *2X,'TIME',9X,'RELATIVE DISPL.',09X,'LEFT',2X,
     *'RIGHT',2X,'LEFT',1X,'RIGHT',3X,'-----LEFT FRONT----  ----RIGHT FRONT-----
     *ONT-----',2X,
     *'LEFT',2X,'RIGHT',1X,'LEFT',2X,'RIGHT',/,
     *9X,'ROLL',  3X,'BODY/BOLSTER',2X,'LATERAL',2X,'FRONT',1X,'FRONT',
     *2X,'REAR',2X,'REAR',10X,'SIDE',2X,'CENTER',2X,'CENTER',
     *2X,'SIDE',10X,'FRONT',1X,'FRONT',1X,'LEFT',2X,'LEFT',
     */,8X,'DISPL.',3X,'LEFT',2X,'RIGHT',3X,'ACCEL.',28X,'TRACK',1X,
     *'BEARING',1X,'PLATE',3X,'PLATE',1X,'BEARING',1X,'TRACK',/,
     *1X,'(SECS)',1X,'(DEG.)' ,2(2X,'(IN.)'),3X,$(G'S) $,1X,4(1X,'(IN.)'
     *),2(1X,3(1X,'(KIPS)')),1X,4(1X,'(IN.)'),/)
10    READ(9,8,END=1000) AA
8     FORMAT(8E15.8)
      DO 20 I=1,2
      AA(I+68)=AA(I+68)/1000.
      AA(I+72)=AA(I+72)/1000.
      AA(I+76)=AA(I+76)/1000.
20    CONTINUE
      DO 30 I=101,104
      AA(I)=-1.*AA(I)
30    CONTINUE
      WRITE(3,101) AA(113),AA(3),AA(109),AA(110),AA(41),(AA(I),I=93,96),
     *AA(77),AA(73), AA(69),AA(70), AA(74),AA(78),(AA(I),I=101,104)
101   FORMAT(F6.2,F8.2,F7.2,F7.2,F8.3,F7.2,F6.2,F7.2,F6.2,F8.1,2F7.1,
     *F8.1,2F7.1,1X,4F6.2)
      GO TO 10
1000  RETURN
      END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. K 05/03/79
      SUBROUTINE MRBL2
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      DO 111 II=1,6
      REWIND 9
      GO TO (112,113,114,115,116,117),II
  112 WRITE (3,119)
      GO TO 118
  113 WRITE (3,120)
      GO TO 118
  114 WRITE (3,121)
      GO TO 118
  115 WRITE (3,122)
      GO TO 118
  116 WRITE (3,123)
      GO TO 118
  117 WRITE (3,124)
      GO TO 118
  118 CONTINUE
8     FORMAT(8E15.8)
  125 READ( 9,8,END=111) AA
      GO TO (126,127,128,129,130,131),II
  126 WRITE (3,2001)AA(113),(AA(I),I=1,10),(AA(I),I=109,112)
      GO TO 125
  127 WRITE (3,2002)AA(113),(AA(I),I=11,20)
      GO TO 125
  128 WRITE (3,2003)AA(113),(AA(I),I=21,30)
      GO TO 125
  129 WRITE (3,2004)AA(113),(AA(I),I=31,40)
      GO TO 125
  130 WRITE (3,2005)AA(113),(AA(I),I=41,50)
      GO TO 125
  131 WRITE (3,2006)AA(113),(AA(I),I=51,60)
      GO TO 125
  111 CONTINUE
      RETURN
  119 FORMAT (1H1,5X,'DISPLACEMENTS OF CARBODY-IN INCH OR DEGREE',//,
     *24X,'CARBODY 1',37X,'CARBODY 2',24X,'CARBODY/BOLSTER',/,11X,'-----
     *--------------------------------', 5X,'---------------------------
     *------------' ,1X,'------------------------------',
     *                //,3X,'TIME',4X,'LAT.',4X,'VERT.',3X,'ROLL',4X,'P
     *ITCH',4X,'YAW',8X,'LAT.',4X,'VERT.',3X,'ROLL',4X,'PITCH',4X,'YAW',
     *6X,'L.F.',4X,'R.F.',4X,'L.R.',4X,'R.R.',/,1X,'(IN SEC.)')
  120 FORMAT (1H1,5X,'DISPLACEMENTS OF BOLSTERS AND WHEELSETS-IN IN. OR
     *DEGREE',//,19X,'FRONT BOLSTER',6X,'REAR BOLSTER',17X,'FRONT WHEELS
     *ET',19X,'REAR WHEELSET',/,14X,'------------------',3X,'-----------
     *---------',4X,'-----------------------------',4X,'----------------
     *-------------',//,7X,'TIME',6X,'VERT.',6X,'ROLL',6X,'VERT.',6X,'RO
     *LL',7X,'LAT.',5X,'VERT.',7X,'ROLL',7X,'LAT.',7X,'VERT.',7X,'ROLL')
  121 FORMAT(1H1,5X,'VELOCITIES OF CARBODY-IN INCH/SEC OR DEG./SEC.',//,
     * 40X,'CARBODY 1',40X,'CARBODY 2',/,17X,'--------------------------
     *-------------------------',8X,'-----------------------------------
     *----------------',//,7X,'TIME',6X,'LAT.',6X,'VERT.',6X,'ROLL',6X,'
     *PITCH',7X,'YAW',9X,'LAT.',8X,'VERT.',6X,'ROLL',6X,'PITCH',7X,'YAW'
     *,/,4X,'(IN SEC.)')
  122 FORMAT (1H1,5X,'VELOCITIES OF BOLSTERS AND WHEELSETS-IN IN/SEC OR
     *DEG/SEC',//,19X,'FRONT BOLSTER',6X,'REAR BOLSTER',17X,'FRONT WHEEL
     *SET',19X,'REAR WHEELSET',/,14X,'------------------',3X,'----------
```

```
     *-----------',4X,'---------------------------',4X,'----------------
     *--------------',//,7X,'TIME',6X,'VERT.',6X,'ROLL',6X,'VERT.',6X,'R
     *OLL',7X,'LAT.',5X,'VERT.',7X,'ROLL',7X,'LAT.',7X,'VERT.',7X,'ROLL'
     *)
  123 FORMAT (1H1,5X,$ACCELERATIONS OF CARBODY IN G'S OR RAD/SEC/SEC$
     *    ,//,40X,'CARBODY 1',40X,'CARBODY 2',/,17X,'-------------------
     *--------------------------------', 10X,'----------------------------
     *-----------------------',//,7X,'TIME',8X,'LAT.',6X,'VERT.',6X,'ROL
     *L',6X,'PITCH',8X,'YAW',9X,'LAT.',8X,'VERT.',6X,'ROLL',6X,'PITCH',7
     *X,'YAW',/,4X,'(IN SEC.)')
  124 FORMAT (1H1,5X,'ACCELERATIONS OF BOLSTERS AND WHEELSETS-IN IN/SEC/
     *SEC OR DEG/SEC/SEC',//,19X,'FRONT BOLSTER',6X,'REAR BOLSTER',17X,'
     *FRONT WHEELSET',19X,'REAR WHEELSET',/,14X,'-------------------',3X
     *,'-------------------',4X,'-----------------------------',4X,'----
     *-------------------------',//,7X,'TIME',6X,'VERT.',6X,'ROLL',6X,'V
     *ERT.',6X,'ROLL',7X,'LAT.',5X,'VERT.',7X,'ROLL',7X,'LAT.',7X,'VERT.
     *',7X,'ROLL')
 2001 FORMAT (6F8.3,4X,5F8.3,1X,4F8.3)
 2002 FORMAT(11F11.5)
 2003 FORMAT (6F11.5,4X,5F11.5)
 2004 FORMAT(11F11.5)
 2005 FORMAT (F11.5,2(2F11.4,3F11.2))
 2006 FORMAT (F11.5,10F11.2)
      END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. K 05/03/79
      SUBROUTINE MRBL3
      COMMON/T2/RR(4),RDD(4),FORP(4),FORG(4),FORW(4),FORWX(4),FORS(4),
     *          DAMBE(4),DAMG(4),DAMW(4),DAMWX(4),DAMS(4),DD(20),EE(20),
     *          AA(113),FORBE(4),DAMSTK(4)
      DO 211 II=1,6
      REWIND 9
      GO TO (212,213,214,215,216,217),II
  212 WRITE (3,219)
      GO TO 218
  213 WRITE (3,220)
      GO TO 218
  214 WRITE (3,221)
      GO TO 218
  215 WRITE(3,222)
      GO TO 218
  216 WRITE(3,223)
      GO TO 218
  217 WRITE(3,224)
      GO TO 218
  218 CONTINUE
8     FORMAT(8E15.8)
  225 READ (9,8,END=211) AA
      GO TO (226,227,228,229,230,231),II
  226 WRITE (3,2007)AA(113),(AA(I),I=61,68)
      GO TO 225
  227 WRITE (3,2008)AA(113),(AA(I),I=69,76)
      GO TO 225
  228 WRITE (3,2009)AA(113),(AA(I),I=77,84)
      GO TO 225
  229 WRITE (3,2010)AA(113),(AA(I),I=85,92)
      GO TO 225
  230 WRITE (3,2011)AA(113),(AA(I),I=93,100)
      GO TO 225
  231 WRITE (3,2012)AA(113),(AA(I),I=101,108)
      GO TO 225
  211 CONTINUE
      RETURN
  219 FORMAT (1H1,5X,'FORCING FUNCTIONS-IN INCHES',//,85X,'DERIVATIVES',
     */,85X,'-----------',//,7X,'TIME',9X,'F.L.',11X,'F.R.',11X,'R.L.',1
     *1X,'R.R.',11X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R.',/,4X,'(IN SE
     *C.)')
  220 FORMAT (1H1,5X,'LOADING ON CENTERPLATES AND SIDE BEARINGS-IN LBS',
     *//,40X,'CENTERPLATE',50X,'SIDE BEARINGS',/,18X,'------------------
     *-----------------------------------',4X,'-------------------------
     *------------------------------'     ,//,6X,'TIME',9X,'F.L.',11X,'F
     *.R.',11X,'R.L.',11X,'R.R.',11X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R
     *.R.',/,2X,'(IN SEC.)')
  221 FORMAT (1H1,5X,'LOADINGS ON TRACK-IN LBS',//,40X,'VERTICAL',50X,'L
     *ATERAL',/,18X,'---------------------------------------------------
     *---',4X,'-------------------------------------------------------'
     *        ,//,6X,'TIME',9X,'F.L.',11X,'F.R.',11X,'R.L.'11X,'R.R.',11
     *X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R.',/,2X,'(IN SEC.)')
  222 FORMAT (1H1,///,25X,'LATERAL LOADING ON BOLSTER-IN LBS',30X,'VERTI
     *CAL DAMPING FORCE-IN LBS',/,18X,'---------------------------------
     *------------------',4X,'------------------------------------------
     *--------------',//,6X,'TIME',9X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'
     *R.R.',11X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R.',/,2X,'(IN SEC.)'
     *)
  223 FORMAT (1H1,///,25X,'SPRING DEFLECTIONS-IN INCHES',35X,'VERTICAL L
```

```
     *OADING ON SPRING-IN LBS',/,18X,'-----------------------------------
     *------------------',4X,'--------------------------------------------
     *-----------',//,6X,'TIME',9X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R
     *.',11X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R.',/,2X,'(IN SEC.)')
  224 FORMAT (1H1,///,25X,'VERTICAL DEFLECTION ON RAIL-IN INCHES',32X,
     *                                                              'LAT
     *ERAL DAMPING-IN LBS',/,18X,'----------------------------------------
     *--------------',4X,'-----------------------------------------------
     *--------',//,6X,'TIME',9X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R.',1
     *1X,'F.L.',11X,'F.R.',11X,'R.L.',11X,'R.R.')
 2007 FORMAT (F10.6,8F15.6)
 2008 FORMAT (F10.6,8F15.2)
 2009 FORMAT (F10.6,8F15.2)
 2010 FORMAT (F10.6,8F15.2)
 2011 FORMAT (F10.6,4F15.6,4F15.2)
 2012 FORMAT (F10.6,4F15.6,4F15.2)
      END
NO ERRORS
SYM3 REV.H
:F
```

```
RDS-500 FORTRAN4 REV. F 04/29/79
      PROGRAM MRBPLT
      INTEGER STAT,C,D,E,F,SUN,B
      INTEGER GHSDUN,TSUB,TCNT,TPTINC
      COMMON/B1/YMAX(113),YMIN(113),IHEADS(40,113),ICHS(113),RANGE,
     * SCALE(113),AXIS(113),MAD(113),YDATA(113),ODATA(113),OERR(6),
     * LHEADS(40,2)
      DATA OERR/5*0.,1./
C        PLOT USES UNIT 8,PLOTP2 USES 8 + 9, PLOTP3 USES 9 + GLD
      CALL PLOTS
      CALL PLOT(.01,.01,-3)
5     CHSDUN=0
      TSUB=113
      LUN=9
C        LUN=9, RECORD IS 109 REAL VALUES
C        NCHS, NO CHANS TO PROCESS - IF ZERO STOP
C        TMAX TIME TO CUT OFF PLOT
C        TMIN TIME TO START PLOT
C        TPTINC PLOT TIME INCREMENT
      READ(2,100)IDUM,NCHS,TMAX,TMIN,TPTINC
100   FORMAT(2I5,2F10.7,I5)
      IF(NCHS)10,1000,10
10    READ(2,102) LHEADS
      DO 20 I=1,NCHS
C        MAX + MIN VALUES FOR SCALING + CHAN TO APPLY IT TO
      READ(2,101) YMAX(I),YMIN(I),ICHS(I)
101   FORMAT(2F10.7,I5)
C        HEADING FOR 1 CHANNEL CORRESPONDING THIS YMAX + YMIN
      READ(2,102) (IHEADS(J,I),J=1,40)
102   FORMAT(40A2)
20    CONTINUE
21    REWIND LUN
      ITIME=IFIX(TMIN)
      IPENCD=3
      TCNT=0
23    MINCH=1 + CHSDUN
      MAXCH=6 + CHSDUN
      DO 210 I=1,TSUB
      ODATA(I)=0.
210   CONTINUE
      IF(NCHS-6)25,30,32
25    MAXCH=NCHS + CHSDUN
30    NCHS=0
      GO TO 34
32    MINCH=MINCH+CHSDUN
      MAXCH=MAXCH+CHSDUN
      NCHS=NCHS-6
C        NO OF PLOTS PERPAGE(MAX 6)
34    NPLOTS=MAXCH-MINCH+1
C        INCHES ALLOWED PER PLOT
      SPACES=10. /NPLOTS
      GAPS=.19
      HEIGHT=.07
      WIDTH=.06
      BOTTOM=.07
      SPACE2=GAPS+2.*BOTTOM+HEIGHT
C        PRINT HEADINGS
      CALL SYMBOL(HEIGHT,1.,HEIGHT,LHEADS(1,1),90.,80)
      X=2.*(HEIGHT+BOTTOM)
      CALL SYMBOL(X,1.,HEIGHT,LHEADS(1,2),90.,80)
```

```
      X=X+.75
      CALL PLOT(X,0.,-3)
      XSTART=X
C
C        LABEL PLOTS + AXES
C
      DO 50 I=MINCH,MAXCH
C
C        PRINT CHANNEL DESCRIPTION FROM CARD
C
      CALL SYMBOL(0.,BOTTOM,HEIGHT,IHEADS(1,I), 0.,80)
      CALL PLOT(0.,0.,3)
C
C        MOVE ORIGIN ABOVE CHANNEL DESCRIPTION
C
      CALL PLOT(0.,GAPS,-3)
      RANGE=YMAX(I)-YMIN(I)
      SCALE(I)=RANGE/(SPACES-GAPS)
      AXIS(I)=-YMIN(I)/SCALE(I)
      MAD(I)=-1
      IF(YMIN(I).EQ.0.) MAD(I)=1
      IF(YMAX(I).EQ.0.) MAD(I)=2
      IF(SIGN(1.,YMIN(I)).EQ.SIGN(1.,YMAX(I))) MAD(I)=0
C
C        COMPUTE E FORM YMIN + PLOT IT IF NOT Y ORIGIN
C
      YPT=YMIN(I)
      CALL XPONT(YPT,X,EXPT,HEIGHT,WIDTH)
      X2=X+2.*WIDTH + .04
      IF(YMIN(I).EQ.0.) GO TO 36
      CALL NUMBER(.02,BOTTOM,HEIGHT,YPT, 0.,4)
      CALL PLOT(0.,0.,3)
      CALL SYMBOL(X,BOTTOM,HEIGHT,'E ', 0.,2)
      CALL PLOT(0.,0.,3)
      CALL NUMBER(X2,BOTTOM,HEIGHT,EXPT, 0.,-1)
      CALL PLOT(0.,0.,3)
36    YAXIS=X2+2.*WIDTH +.04
      Y=BOTTOM+SPACES-SPACE2
C
C        COMPUTE E FORM YMAX + PLOT IT IF NOT Y ORIGIN
C
      YPT=YMAX(I)
      CALL XPONT(YPT,X2,EXPT,HEIGHT,WIDTH)
      X=X2+2.*WIDTH + .04
      IF(YMAX(I).EQ.0.) GO TO 37
      CALL NUMBER(.02,Y,HEIGHT,YPT, 0.,4)
      CALL PLOT(0.,0.,3)
      CALL SYMBOL(X2,Y,HEIGHT,'E ', 0., 2)
      CALL PLOT(0.,0.,3)
      CALL NUMBER(X,Y,HEIGHT,EXPT, 0.,-1)
      CALL PLOT(0.,0.,3)
C
C        CHOOSE MAX X FOR X ORIGIN LINE
C
37    X=AMAX1(YAXIS,X+2.*WIDTH+.04)+.02
C        IF Y AXIS PLOT Y ZERO POINT
      IF(MAD(I)) 38,39,40
38    Y=AXIS(I)-HEIGHT/2.
380   X=X-(WIDTH*3.+.04)
      CALL SYMBOL(X,Y,HEIGHT,',0',0.,2)
```

```
      CALL PLOT(0.,0.,3)
      X=X-(WIDTH*5.+.04)
      CALL NUMBER(X,Y,HEIGHT,TMIN,0.,2)
      CALL PLOT(0.,0.,3)
      X=X+(WIDTH* 8.+.08)
39    X=X+1.
      CALL SYMBOL(X,BOTTOM,HEIGHT,'TIME(SECS)',0.,10)
      X=X-1.
      GO TO 43
40    K=MAD(I)
      GO TO (41,380),K
41    Y=BOTTOM
      GO TO 380
43    Y=SPACES-GAPS
      CALL PLOT(X,0.,3)
      CALL PLOT(X,Y,2)
      XORIG=X
      CALL PLOT(0.,Y,2)
45    CALL PLOT(0.,Y,-3)
      YMAX(I)=YMAX(I)/SCALE(I)
      YMIN(I)=YMIN(I)/SCALE(I)
      X=XSTART
50    CONTINUE
51    START=XORIG-TMIN
      OX=TMIN
C        SET ORIGIN FOR PLOTS
      Y=-10.+GAPS
      CALL PLOT(START,Y,-3)
C
C        READ DATA TAPE
C
55    READ(LUN,103,END= 70  )(YDATA(J),J=1,TSUB)
103   FORMAT(8E15.8)
      TCNT=TCNT+1
      IF(MOD(TCNT,TPTINC))55,60,55
60    IF(YDATA(TSUB).LT.TMIN) GO TO 55
      J=1
C
C        PLOT CHANNEL DATA,AXES,+BOUNDS FOR ONE RECORD (ONE TIME SAMPLE)
C
      DO 65 I=MINCH,MAXCH
      YINC=SPACES*(J-1)+AXIS(I)
C        PLOT BOUNDS THIS PLOT
      Y=YMIN(I)+YINC
      CALL PLOT(OX,Y,3)
      CALL PLOT(YDATA(TSUB),Y,2)
      CALL PLOT(0.,0.,3)
      Y=YMAX(I)+YINC
      CALL PLOT(OX,Y,3)
      CALL PLOT(YDATA(TSUB),Y,2)
      CALL PLOT(0.,0.,3)
      YINC2=YINC
C        PLOT AXIS THIS PLOT
      IF(MAD(I))61,610,61
610   YINC2=YINC+YMAX(I)
61    CALL PLOT(OX,YINC2,3)
      CALL PLOT(YDATA(TSUB),YINC2,2)
      CALL PLOT(0.,0.,3)
      IF(IFIX(YDATA(TSUB)).LE.ITIME) GO TO 62
C
```

```
C         PLOT TICK MARKS AND SEC NOS
C
      X=YDATA(TSUB)-WIDTH/2.
      Y=YMIN(I)+YINC+BOTTOM-.02
      CALL PLOT(X,Y,3)
      Y=Y-BOTTOM+.02
      CALL PLOT(X,Y,2)
      Y=YMAX(I)+YINC-BOTTOM+.02
      CALL PLOT(X,Y,3)
      Y=Y+BOTTOM-.02
      CALL PLOT(X,Y,2)
      Y=Y-(HEIGHT+BOTTOM+.04)
      CALL NUMBER(X,Y,HEIGHT,YDATA(TSUB),0.,-1)
      CALL PLOT(0.,0.,3)
62    Y=ODATA(I)+YINC
      CALL PLOT(OX,Y,3)
      THISY=YDATA(ICHS(I))/SCALE(I)
      IF(THISY.GT.YMAX(I)) THISY=YMAX(I)
      IF(THISY.LT.YMIN(I)) THISY=YMIN(I)
      Y=THISY+YINC
      ODATA(I)=THISY
      CALL PLOT(YDATA(TSUB),Y,IPENCD)
      CALL PLOT(0.,0.,3)
      J=J+1
65    CONTINUE
      IPENCD=2
      IF(IFIX(YDATA(TSUB)).GT.ITIME) ITIME=IFIX(YDATA(TSUB))
C
C         MOVE PLOTTED DATA TO OLD
C
      OX=YDATA(TSUB)
      IF(OX.GE.TMAX) GO TO 70
C
C         LOOP BACK TO READ NEXT RECORD
C
      GO TO 55
70    CHSDUN=CHSDUN+NPLOTS
      CALL PLOT(-START,-GAPS,3)
      CALL PLOT(OX,-GAPS,2)
      X=OX+1.
72    IF(X.GT.4.8) GO TO 75
      X=X+1.
      GO TO 72
75    CALL PLOT(X,-GAPS,-3)
      IF(NCHS)21,5,21
1000  CALL PLOT(0.,0.,999)
      STOP
      END
NO ERRORS
SYM3 REV.G
:F
```

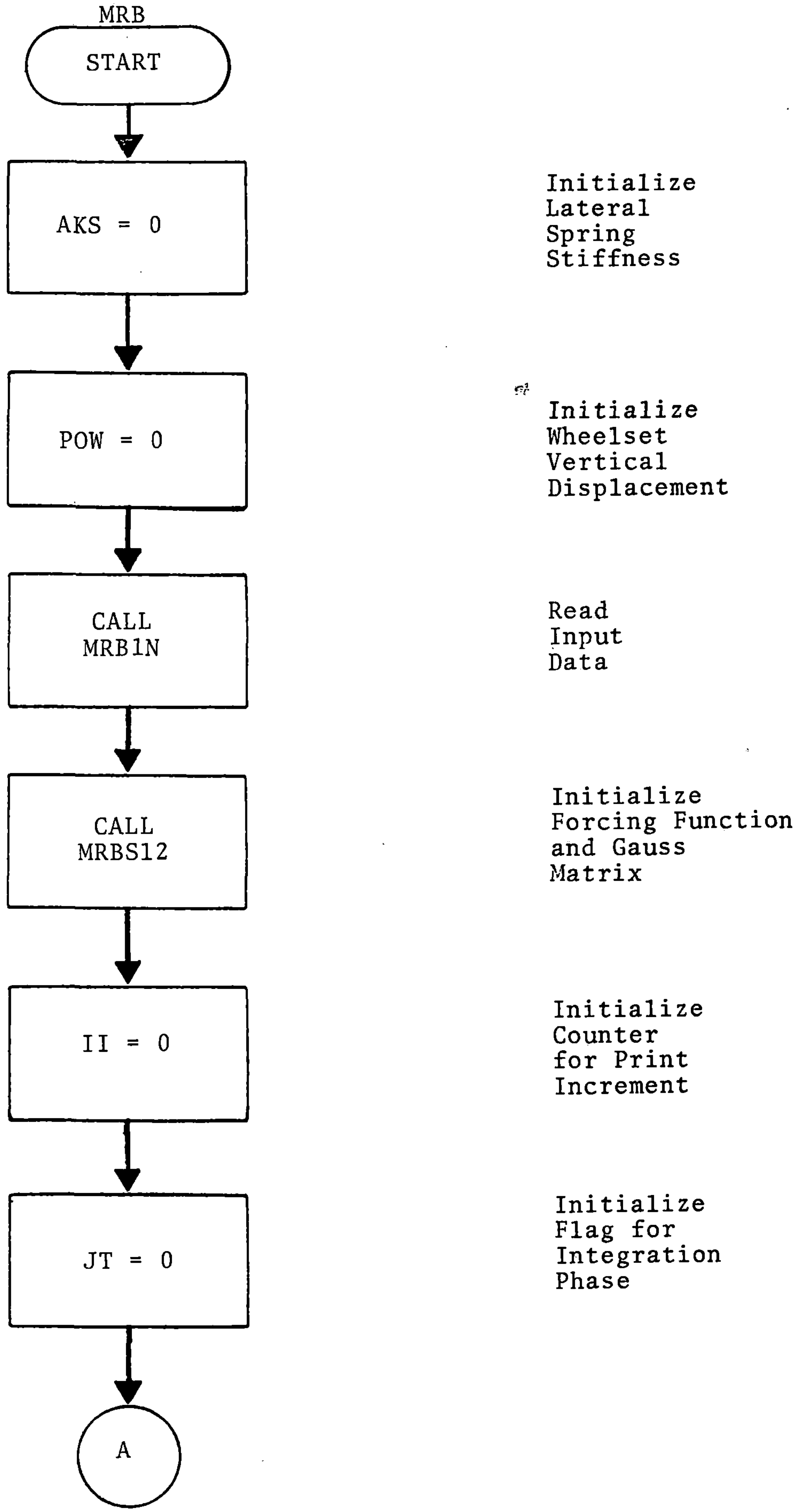
```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE XPONT(Y,ESPAC,EXPT,HEIGHT,WIDTH)
      EXPT=0.
      IF(Y.EQ.0.) GO TO 200
      YFIX=1.
      IF(ABS(Y).LT..0001) YFIX=10.
      IF(ABS(Y).GT.9999.) YFIX=.1
      IF(YFIX.EQ.1.) GO TO 100
10    Y=Y*YFIX
      EXPT=EXPT+1.
      IF(ABS(Y).LT.1.) GO TO 10
      IF(ABS(Y).GT.9.) GO TO 10
      IF(YFIX.EQ.10.) EXPT=-EXPT
100   ESPAC=8.*WIDTH + .09
      RETURN
200   Y=.000001
      GO TO 100
      END
NO ERRORS
SYM3 REV.G
:F
```

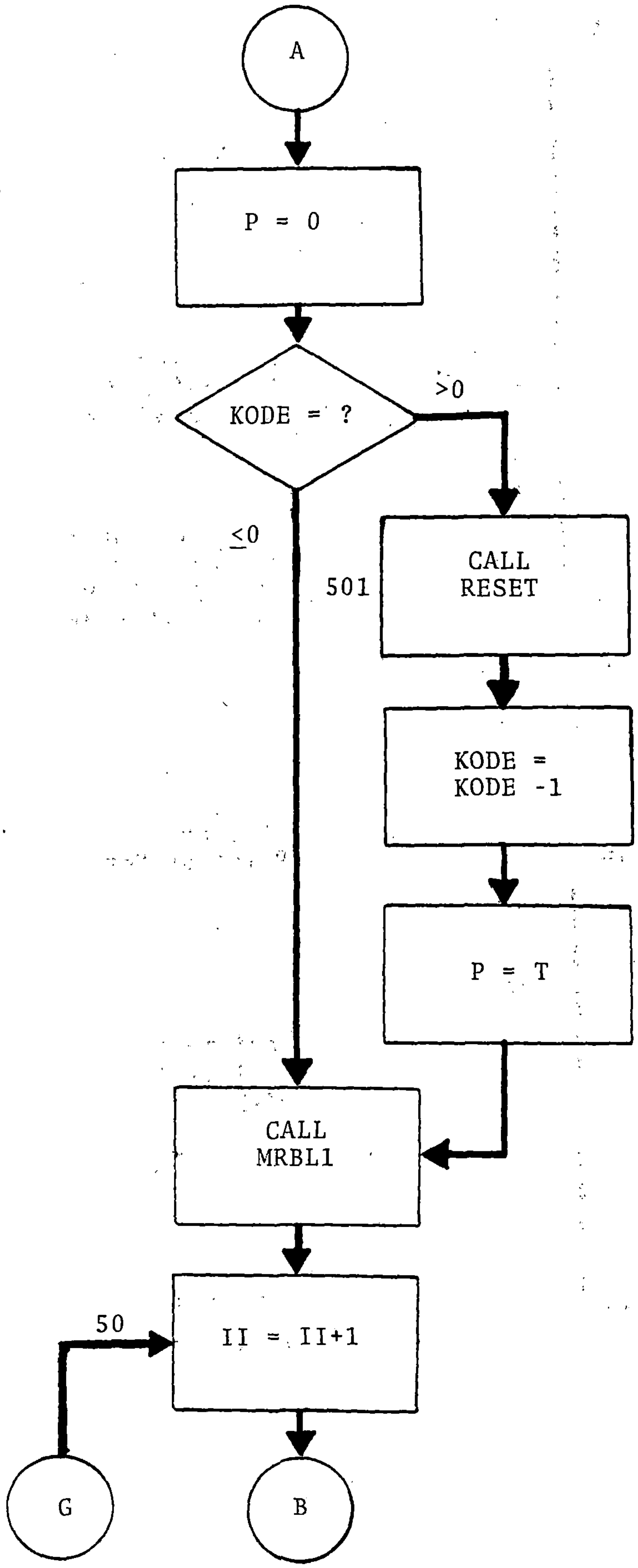
```
RDS-500 FORTRAN4 REV. F 04/29/79
      SUBROUTINE XPONT(Y,ESPAC,EXPT,HEIGHT,WIDTH)
      EXPT=0.
      IF(Y.EQ.0.) GO TO 200
      YFIX=1.
      IF(ABS(Y).LT..0001) YFIX=10.
      IF(ABS(Y).GT.9999.) YFIX=.1
      IF(YFIX.EQ.1.) GO TO 100
10    Y=Y*YFIX
      EXPT=EXPT+1.
      IF(ABS(Y).LT.1.) GO TO 10
      IF(ABS(Y).GT.9.) GO TO 10
      IF(YFIX.EQ.10.) EXPT=-EXPT
100   ESPAC=8.*WIDTH + .09
      RETURN
200   Y=.000001
      GO TO 100
      END
NO ERRORS
SYM3 REV.G
:F
```

APPENDIX C

PROGRAM FLOW CHART

5


MRB
START
AKS = 0
Initialize Lateral Spring Stiffness
POW = 0
Initialize Wheelset Vertical Displacement
CALL MRB1N
Read Input Data
CALL MRBS12
Initialize Forcing Function and Gauss Matrix
II = 0
Initialize Counter for Print Increment
JT = 0
Initialize Flag for Integration Phase
A



Initialize Partial Time Indicator for Time Within an Integration Step.

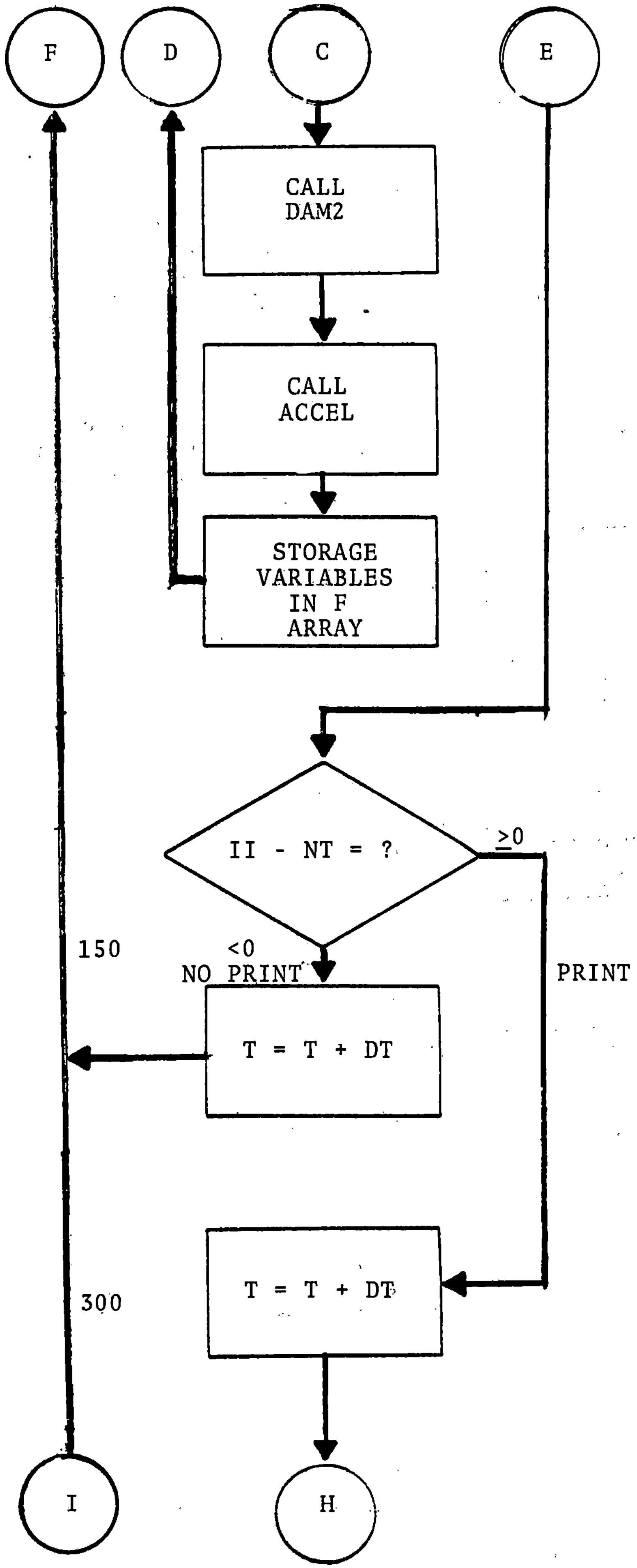
Choose Restart Mode, Start from Equilibrium if Greater than Zero; Start from Previous Run End if Less than or Equal to Zero

Reset Values from Those Stored in Previous Run

Set Value of Kode for Storage When Reset is Again Called.

Set Time from Previous Run

Increment Print Counter



Calculate Damping Forces

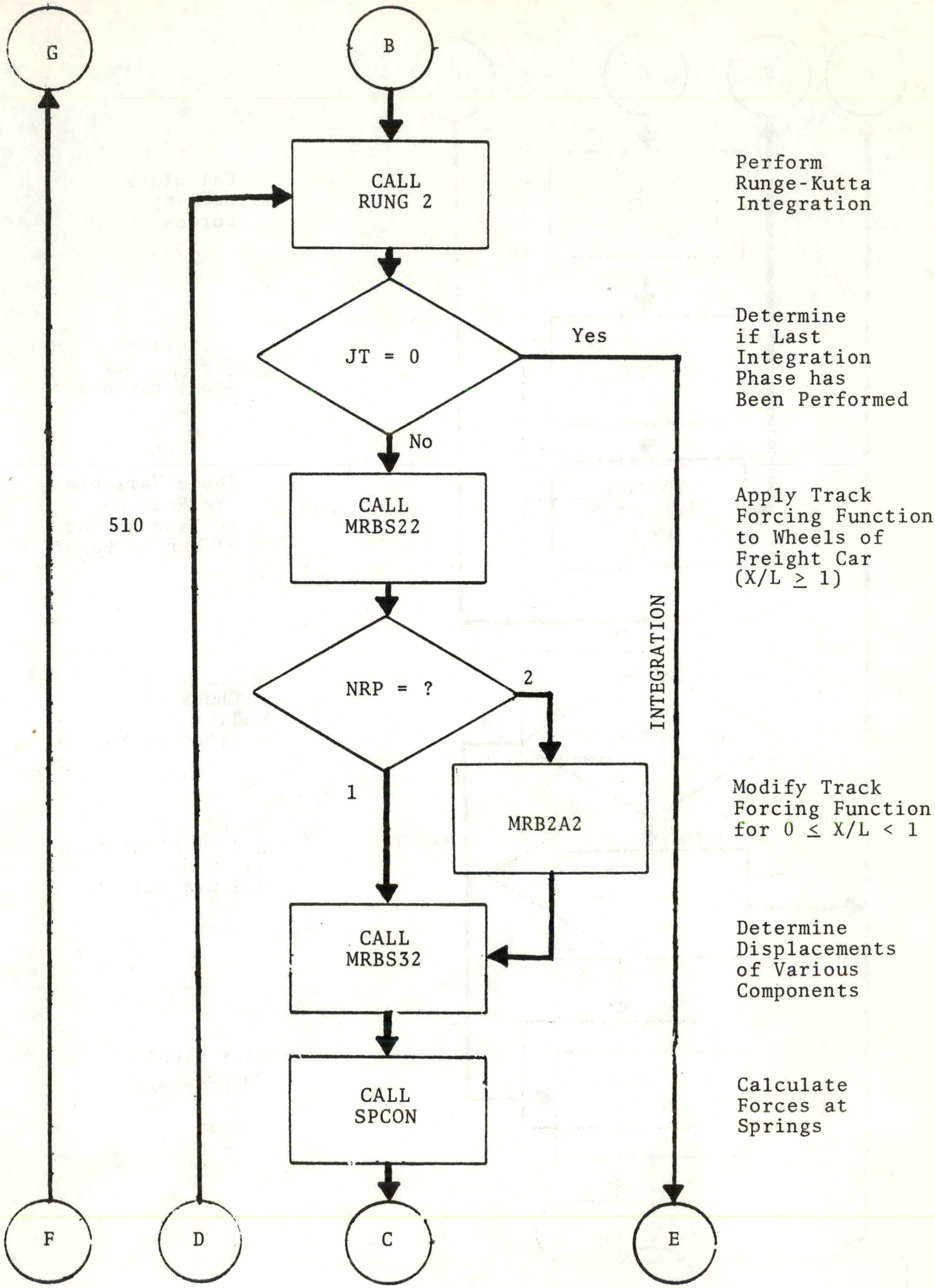
Calculate Freight Car Accelerations

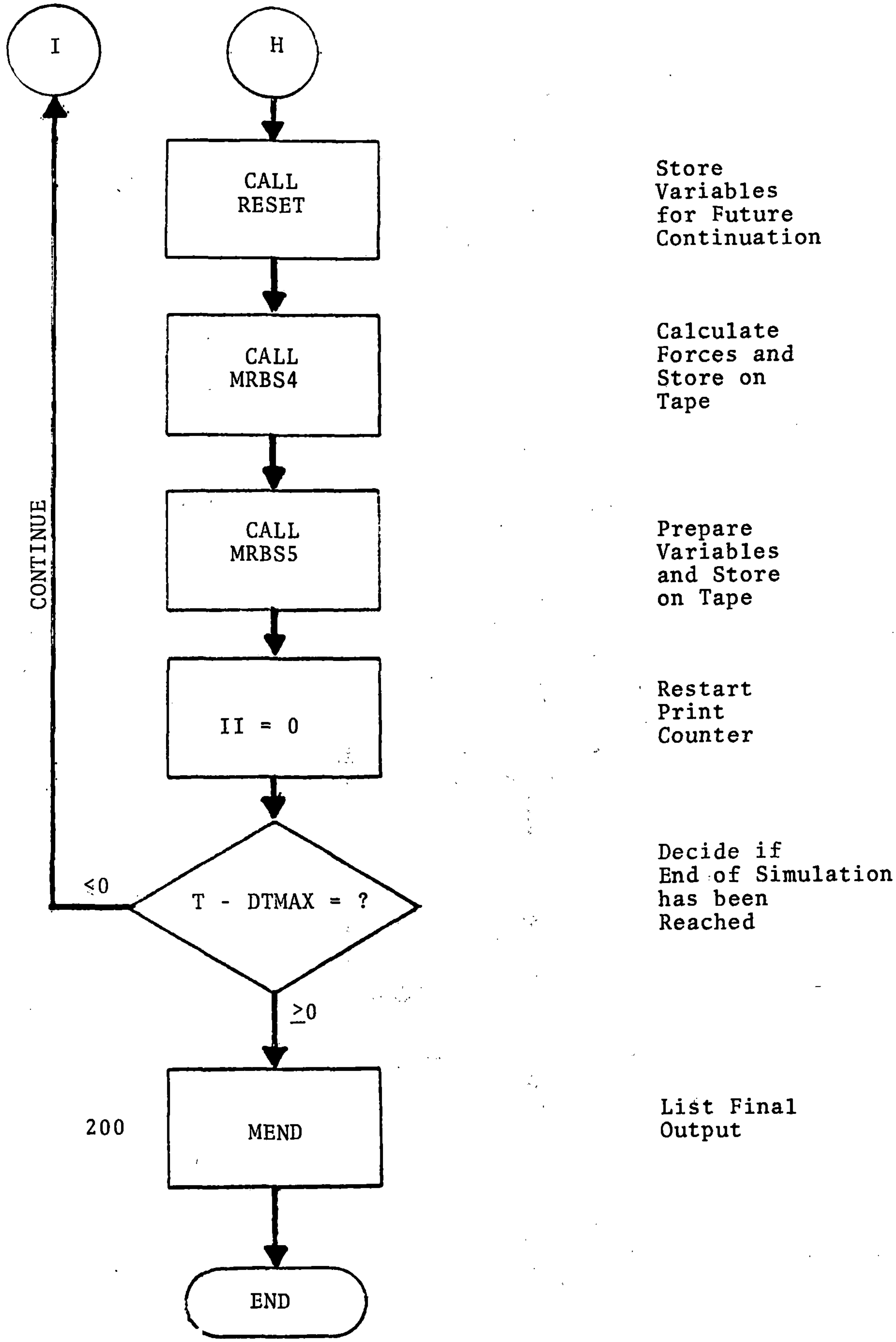
These Variables are Read on to Tape at End of Run in Reset

Check if Time to Print or Not

Increment Full Time Step

Increment Full Time Step


G
B
CALL
RUNG 2
Perform
Runge-Kutta
Integration
JT = 0
Yes
No
Determine
if Last
Integration
Phase has
Been Performed
510
CALL
MRBS22
Apply Track
Forcing Function
to Wheels of
Freight Car
(X/L ≥ 1)
INTEGRATION
NRP = ?
2
1
MRB2A2
Modify Track
Forcing Function
for 0 ≤ X/L < 1
CALL
MRBS32
Determine
Displacements
of Various
Components
CALL
SPCON
Calculate
Forces at
Springs
F
D
C
E



I
H
CALL
RESET
Store
Variables
for Future
Continuation
CALL
MRBS4
Calculate
Forces and
Store on
Tape
CALL
MRBS5
Prepare
Variables
and Store
on Tape
CONTINUE
II = 0
Restart
Print
Counter
T - DTMAX = ?
<0
Decide if
End of Simulation
has been
Reached
≥0
200
MEND
List Final
Output
END

APPENDIX D

COMPUTER SIMULATION INPUTS

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
I. CAR DIMENSIONS Moments of Inertia: Front Mass Pitching	AIX1	$lb\text{-}ft\text{-}sec^2$	79,694	97,464	
Front Mass Rolling	AIY1	$lb\text{-}ft\text{-}sec^2$	29,607	40,356	
Front Mass Yawing	AIZ1	$lb\text{-}ft\text{-}sec^2$	72,422	82,905	
Rear Mass Pitching	AIX2	$lb\text{-}ft\text{-}sec^2$	79,694	89,559	
Rear Mass Rolling	AIY2	$lb\text{-}ft\text{-}sec^2$	29,607	32,284	
Rear Mass Yawing	AIZ2	$lb\text{-}ft\text{-}sec^2$	72,422	77,968	
Front Bolster Rolling	AIY3	$lb\text{-}ft\text{-}sec^2$	180	180	
Rear Bolster Rolling	AIY4	$lb\text{-}ft\text{-}sec^2$	180	180	
Front Wheelset/Frame Rolling	AIY5	$lb\text{-}ft\text{-}sec^2$	1363.2	1363.2	
Rear Wheelset/Frame Rolling	AIY6	$lb\text{-}ft\text{-}sec^2$	1363.2	1363.2	
Masses: Front Car Body	AM1	slugs	1,719	2,270	
Rear Car Body	AM2	slugs	1,719	1,727	
Front Bolster	AM3	slugs	36	36	
Rear Bolster	AM4	slugs	36	36	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
Front Wheelset	AM5	slugs	198	198	
Rear Wheelset	AM6	slugs	198	198	
Distances: Front Left Centerplate Radius	P1	ft	0.583	0.583	
Front Right Centerplate Radius	P2	ft	0.583	0.583	
Rear Left Centerplate Radius	P3	ft	0.583	0.583	
Rear Right Centerplate Radius	P4	ft	0.583	0.583	
Front Left Side Bearing to Bolster Centerline	BE1	ft	2.083	2.083	
Front Right Side Bearing to Bolster Centerline	BE2	ft	2.083	2.083	
Rear Left Side Bearing to Bolster Centerline	BE3	ft	2.083	2.083	
Rear Right Side Bearing to Bolster Centerline	BE4	ft	2.083	2.083	
Front Left Spring to Bolster Center	G1	ft	3.29	3.29	
Front Right Spring to Bolster Center	G2	ft	3.29	3.29	
Rear Left Spring to Bolster Center	G3	ft	3.29	3.29	
Rear Right Spring to Bolster Center	G4	ft	3.29	3.29	
Front Left Half of Gage	W1	ft	2.375	2.375	
Front Right Half of Gage	W2	ft	2.375	2.375	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
Rear Left Half of Gage	W3	ft	2.375	2.375	
Rear Right Half of Gage	W4	ft	2.375	2.375	
Front Wheelset c.g. to Front Left Side Spring	S1	ft	0.17	0.17	
Front Wheelset c.g. to Front Right Side Spring	S2	ft	0.17	0.17	
Rear Wheelset c.g. to Front Left Side Spring	S3	ft	0.17	0.17	
Rear Wheelset c.g. to Front Right Side Spring	S4	ft	0.17	0.17	
Heights:					
Front Left Side Bearing Clearance	ZB1	ft	0.021	0.021	
Front Right Side Bearing Clearance	ZB2	ft	0.021	0.021	
Rear Left Side Bearing Clearance	ZB3	ft	0.021	0.021	
Rear Right Side Bearing Clearance	ZB4	ft	0.021	0.021	
Front Left c.g. Wheelsets From Rail	C1	ft	1.5	1.5	
Front Right c.g. Wheelsets From Rail	C2	ft	1.5	1.5	
Rear Left c.g. Wheelsets From Rail	C3	ft	1.5	1.5	
Rear Right c.g. Wheelsets From Rail	C4	ft	1.5	1.5	
c.g. Bolster to c.g. Carbody Vertical Front	B1	ft	4.17	4.67	
c.g. Bolster to c.g. Carbody Vertical Rear	B2	ft	4.17	4.67	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
c.g. Bolster to c.g. Carbody Longitudinal Front	D1	ft	11.41	12.7	
c.g. Bolster to c.g. Carbody Longitudinal Rear	D2	ft	11.41	13.2	
Front Left Gib Clearance	XSC1	ft	0.0313	0.0313	
Front Right Gib Clearance	XSC2	ft	0.0313	0.0313	
Rear Left Gib Clearance	XSC3	ft	0.0313	0.0313	
Rear Right Gib Clearance	XSC4	ft	0.0313	0.0313	
Front Left Flange Clearance	CW1	ft	0.0339	0.0339	
Front Right Flange Clearance	CW2	ft	0.0339	0.0339	
Rear Left Flange Clearance	CW3	ft	0.0339	0.0339	
Rear Right Flange Clearance	CW4	ft	0.0339	0.0339	
c.g. Front Body to c.g. Whole Body	D1PI	ft	8.44	7.17	
c.g. Rear Body to c.g. Whole Body	D2PI	ft	8.44	6.67	
II. INPUT CURVE PARAMETERS Speed	V	ft/sec	14.67-52.80	14.67-52.80	
Rail Length	AL	ft	39.0	39.0	
Max Crosslevel Difference	S	ft	0.0313	0.0313	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
Truck Center Distance	D	ft	39.71	39.71	
Wheel Base	B	ft	5.67	5.67	
III. STIFFNESS PARAMETERS Front Left Centerplate Vertical	GKP_1	lb/ft	25,440,000	25,440,000	
Front Right Centerplate Vertical	GKP_2	lb/ft	25,440,000	25,440,000	
Rear Left Centerplate Vertical	GKP_3	lb/ft	25,440,000	25,440,000	
Rear Right Centerplate Vertical	GKP_4	lb/ft	25,440,000	25,440,000	
Front Left Side Bearing Vertical	$GKBE_1$	lb/ft	42,960,000	42,960,000	
Front Right Side Bearing Vertical	$GKBE_2$	lb/ft	42,960,000	42,960,000	
Rear Left Side Bearing Vertical	$GKBE_3$	lb/ft	42,960,000	42,960,000	
Rear Right Side Bearing Vertical	$GKBE_4$	lb/ft	42,960,000	42,960,000	
Corresponding Damping Type	$CDBE_{1,2,3,4}$	0 Viscous 1 Coulomb	0	0	
Corresponding Damping Coefficient	$GDBE_{1,2,3,4}$	lbs/ft/sec or lbs	500	500	
Front Left Suspension Vertical	GKG_1	lb/ft	283,622	249,485	
Front Right Suspension Vertical	GKG_2	lb/ft	283,622	249,485	
Rear Left Suspension Vertical	GKG_3	lb/ft	283,622	249,485	
Rear Right Suspension Vertical	GKG_4	lb/ft	283,622	249,485	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
Corresponding Damping Type	$CDG_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	
Corresponding Damping Coefficient	$GDG_{1,2,3,4}$	lbs or lbs/ft/sec	4,000	4,000	
Front Left Suspension Lateral	GKS_1	lb/ft	130,466	114,763	
Front Right Suspension Lateral	GKS_2	lb/ft	130,466	114,763	
Rear Left Suspension Lateral	GKS_3	lb/ft	130,466	114,763	
Rear Right Suspension Lateral	GKS_4	lb/ft	130,466	114,763	
Corresponding Damping Type	$CDS_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	
Corresponding Damping Coefficient	$GDS_{1,2,3,4}$	lbs or lbs/ft/sec	4,000	4,000	
Front Left Track Vertical	GKW_1	lb/ft	3,000,000	3,000,000	
Front Right Track Vertical	GKW_2	lb/ft	3,000,000	3,000,000	
Rear Left Track Vertical	GKW_3	lb/ft	3,000,000	3,000,000	
Rear Right Track Vertical	GKW_4	lb/ft	3,000,000	3,000,000	
Corresponding Damping Type	$CDW_{1,2,3,4}$	0 Viscous 1 Coulomb	0	0	
Corresponding Damping Coefficient	$GDW_{1,2,3,4}$	lbs/ft/sec	0.0	0.0	
Front Left Track Lateral	$GKWX_1$	lb/ft	2,000,000	2,000,000	
Front Right Track Lateral	$GKWX_2$	lb/ft	2,000,000	2,000,000	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
Rear Left Track Lateral	$GKWX_3$	lb/ft	2,000,000	2,000,000	
Rear Right Track Lateral	$GKWX_4$	lb/ft	2,000,000	2,000,000	
Corresponding Damping Type	$CDWX_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	
Corresponding Damping Coefficient	$GDWX_{1,2,3,4}$	lbs or lbs/ft/sec	0.0	0.0	
Tirsional Between Body Masses	T12	ft/lbs/rad	5.35×10^7	5.35×10^7	
Shearing Between Body of the Vertical Axis	B12Z	ft/lbs	0.0	0.0	
Shearing Between Body in Lateral Direction	B12X	ft/lbs	0.0	0.0	
Torsional Damping Between Bodies	D12	ft/lbs/rad/sec	0.0	0.0	
Bending Between Bodies About Lateral Axis	T12X	ft/lbs/rad	2×10^8	2×10^8	
Bending Between Bodies About Vertical Axis	T12Z	ft/lbs/rad	4×10^8	4×10^8	
Length of Spring Travel	POGC	ft	0.255	0.255	
Side Frame Lateral	SFLAT	lb/ft	1,000,000	1,000,000	
Side Frame Vertical	SFVER	lb/ft	38,520,000	38,520,000	
Friction Coefficient at Gib	COEFF	Dimensionless	0.3	0.3	

VEHICLE NUMBER 39551

Description	Variable Name	Units	Validation	A	B
IV. MODEL TIME PARAMETERS Time Increment	DT	seconds	0.0005	0.0005	
Time Model to Pause	DTMAX	seconds	16	12	
Number of Time Increments Between Printouts	NT	Dimensionless	100	100	
V. MODEL MODE PARAMETERS Rolling Mode Flag	NRP	0 off 1 on		1.0	
Bouncing Mode Number of Joints	NDJ			1.0	

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
I. CAR DIMENSIONS Moments of Inertia: Front Mass Pitching	AIX1	lb-ft-sec^2	126,334		
Front Mass Rolling	AIY1	lb-ft-sec^2	33,640		
Front Mass Yawing	AIZ1	lb-ft-sec^2	75,295		
Rear Mass Pitching	AIX2	lb-ft-sec^2	126,334		
Rear Mass Rolling	AIY2	lb-ft-sec^2	33,640		
Rear Mass Yawing	AIZ2	lb-ft-sec^2	75,295		
Front Bolster Rolling	AIY3	lb-ft-sec^2	270		
Rear Bolster Rolling	AIY4	lb-ft-sec^2	270		
Front Wheelset/Frame Rolling	AIY5	lb-ft-sec^2	2,045		
Rear Wheelset/Frame Rolling	AIY6	lb-ft-sec^2	2,045		
Masses: Front Car Body	AM1	slugs	2,035		
Rear Car Body	AM2	slugs	2,035		
Front Bolster	AM3	slugs	54		
Rear Bolster	AM4	slugs	54		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
Front Wheelset	AM5	slugs	297		
Rear Wheelset	AM6	slugs	297		
Distances: Front Left Centerplate Radius	P1	ft	0.75		
Front Right Centerplate Radius	P2	ft	0.75		
Rear Left Centerplate Radius	P3	ft	0.75		
Rear Right Centerplate Radius	P4	ft	0.75		
Front Left Side Bearing to Bolster Centerline	BE1	ft	2.0		
Front Right Side Bearing to Bolster Centerline	BE2	ft	2.0		
Rear Left Side Bearing to Bolster Centerline	BE3	ft	2.0		
Rear Right Side Bearing to Bolster Centerline	BE4	ft	2.0		
Front Left Spring to Bolster Center	G1	ft	3.29		
Front Right Spring to Bolster Center	G2	ft	3.29		
Rear Left Spring to Bolster Center	G3	ft	3.29		
Rear Right Spring to Bolster Center	G4	ft	3.29		
Front Left Half of Gage	W1	ft	2.375		
Front Right Half of Gage	W2	ft	2.375		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
Rear Left Half of Gage	W3	ft	2.375		
Rear Right Half of Gage	W4	ft	2.375		
Front Wheelset c.g. to Front Left Side Spring	S1	ft	0.17		
Front Wheelset c.g. to Front Right Side Spring	S2	ft	0.17		
Rear Wheelset c.g. to Front Left Side Spring	S3	ft	0.17		
Rear Wheelset c.g. to Front Right Side Spring	S4	ft	0.17		
Heights: Front Left Side Bearing Clearance	ZB1	ft	0.021		
Front Right Side Bearing Clearance	ZB2	ft	0.021		
Rear Left Side Bearing Clearance	ZB3	ft	0.021		
Rear Right Side Bearing Clearance	ZB4	ft	0.021		
Front Left c.g. Wheelsets From Rail	C1	ft	1.38		
Front Right c.g. Wheelsets From Rail	C2	ft	1.38		
Rear Left c.g. Wheelsets From Rail	C3	ft	1.38		
Rear Right c.g. Wheelsets From Rail	C4	ft	1.38		
c.g. Bolster to c.g. Carbody Vertical Front	B1	ft	5.0		
c.g. Bolster to c.g. Carbody Vertical Rear	B2	ft	5.0		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
c.g. Bolster to c.g. Carbody Longitudinal Front	D1	ft	10.4		
c.g. Bolster to c.g. Carbody Longitudinal Rear	D2	ft	10.4		
Front Left Gib Clearance	XSC1	ft	0.0313		
Front Right Gib Clearance	XSC2	ft	0.0313		
Rear Left Gib Clearance	XSC3	ft	0.0313		
Rear Right Gib Clearance	XSC4	ft	0.0313		
Front Left Flange Clearance	CW1	ft	0.0339		
Front Right Flange Clearance	CW2	ft	0.0339		
Rear Left Flange Clearance	CW3	ft	0.0339		
Rear Right Flange Clearance	CW4	ft	0.0339		
c.g. Front Body to c.g. Whole Body	D1PI	ft	7.6		
c.g. Rear Body to c.g. Whole Body	D2PI	ft	7.6		
II. INPUT CURVE PARAMETERS Speed	V	ft/sec	14.67 - 52.80		
Rail Length	AL	ft	39.0		
Max Crosslevel Difference	S	ft	0.031		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
Truck Center Distance	D	ft	36.0		
Wheel Base	B	ft	9.0		
III. STIFFNESS PARAMETERS					
Front Left Centerplate Vertical	GKP_1	lb/ft	38,160,000		
Front Right Centerplate Vertical	GKP_2	lb/ft	38,160,000		
Rear Left Centerplate Vertical	GKP_3	lb/ft	38,160,000		
Rear Right Centerplate Vertical	GKP_4	lb/ft	38,160,000		
Front Left Side Bearing Vertical	$GKBE_1$	lb/ft	64,440,000		
Front Right Side Bearing Vertical	$GKBE_2$	lb/ft	64,440,000		
Rear Left Side Bearing Vertical	$GKBE_3$	lb/ft	64,440,000		
Rear Right Side Bearing Vertical	$GKBE_4$	lb/ft	64,440,000		
Corresponding Damping Type	$CDBE_{1,2,3,4}$	0 Viscous 1 Coulomb	0		
Corresponding Damping Coefficient	$GDBE_{1,2,3,4}$	lbs/ft/sec or lbs	500		
Front Left Suspension Vertical	GKG_1	lb/ft	412,646		
Front Right Suspension Vertical	GKG_2	lb/ft	412,646		
Rear Left Suspension Vertical	GKG_3	lb/ft	412,646		
Rear Right Suspension Vertical	GKG_4	lb/ft	412,646		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
Corresponding Damping Type	$CDG_{1,2,3,4}$	0 Viscous 1 Coulomb	1		
Corresponding Damping Coefficient	$GDG_{1,2,3,4}$	lbs or lbs/ft/sec	8,000		
Front Left Suspension Lateral	GKS_1	lb/ft	189,817		
Front Right Suspension Lateral	GKS_2	lb/ft	189,817		
Rear Left Suspension Lateral	GKS_3	lb/ft	189,817		
Rear Right Suspension Lateral	GKS_4	lb/ft	189,817		
Corresponding Damping Type	$CDS_{1,2,3,4}$	0 Viscous 1 Coulomb	1		
Corresponding Damping Coefficient	$GDS_{1,2,3,4}$	lbs or lbs/ft/sec	8,000		
Front Left Track Vertical	GKW_1	lb/ft	4,500,000		
Front Right Track Vertical	GKW_2	lb/ft	4,500,000		
Rear Left Track Vertical	GKW_3	lb/ft	4,500,000		
Rear Right Track Vertical	GKW_4	lb/ft	4,500,000		
Corresponding Damping Type	$CDW_{1,2,3,4}$	0 Viscous 1 Coulomb	0		
Corresponding Damping Coefficient	$GDW_{1,2,3,4}$	lbs/ft/sec	0.0		
Front Left Track Lateral	$GKWX_1$	lb/ft	3,000,000		
Front Right Track Lateral	$GKWX_2$	lb/ft	3,000,000		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
Rear Left Track Lateral	$GKWX_3$	lb/ft	3,000,000		
Rear Right Track Lateral	$GKWX_4$	lb/ft	3,000,000		
Corresponding Damping Type	$CDWX_{1,2,3,4}$	0 Viscous 1 Coulomb	1		
Corresponding Damping Coefficient	$GDWX_{1,2,3,4}$	lbs or lbs/ft/sec	0.0		
Tirsional Between Body Masses	T12	ft/lbs/rad	6.65×10^7		
Shearing Between Body of the Vertical Axis	B12Z	ft/lbs	0.0		
Shearing Between Body in Lateral Direction	B12X	ft/lbs	0.0		
Torsional Damping Between Bodies	D12	ft/lbs/rad/sec	0.0		
Bending Between Bodies About Lateral Axis	T12X	ft/lbs/rad	2×10^8		
Bending Between Bodies About Vertical Axis	T12Z	ft/lbs/rad	4×10^8		
Length of Spring Travel	POGC	ft	0.21		
Side Frame Lateral	SFLAT	lb/ft	1,500,000		
Side Frame Vertical	SFVER	lb/ft	57,780,000		
Friction Coefficient at Gib	COEFF	Dimensionless	0.3		

VEHICLE NUMBER 38444

Description	Variable Name	Units	Validation	A	B
IV. MODEL TIME PARAMETERS Time Increment	DT	seconds	0.0005		
Time Model to Pause	DTMAX	seconds	12		
Number of Time Increments Between Printouts	NT	Dimensionless	100		
V. MODEL MODE PARAMETERS Rolling Mode Flag	NRP	0 off 1 on	1		
Bouncing Mode Number of Joints	NDJ		1		

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
I. CAR DIMENSIONS					
Moments of Inertia:					
Front Mass Pitching	AIX1	lb-ft-sec^2	538,679	588,603	556,825
Front Mass Rolling	AIY1	lb-ft-sec^2	188,000	181,841	141,510
Front Mass Yawing	AIZ1	lb-ft-sec^2	484,961	527,160	512,709
Rear Mass Pitching	AIX2	lb-ft-sec^2	538,679	588,603	556,825
Rear Mass Rolling	AIY2	lb-ft-sec^2	188,000	181,841	141,510
Rear Mass Yawing	AIZ2	lb-ft-sec^2	484,961	527,160	512,709
Front Bolster Rolling	AIY3	lb-ft-sec^2	360	360	360
Rear Bolster Rolling	AIY4	lb-ft-sec^2	360	360	360
Front Wheelset/Frame Rolling	AIY5	lb-ft-sec^2	2,726	2,726	2,726
Rear Wheelset/Frame Rolling	AIY6	lb-ft-sec^2	2,726	2,726	2,726
Masses:					
Front Car Body	AM1	slugs	5,400	5,643	4,649
Rear Car Body	AM2	slugs	5,400	5,643	4,649
Front Bolster	AM3	slugs	144	144	144
Rear Bolster	AM4	slugs	144	144	144

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
Front Wheelset	AM5	slugs	360	360	360
Rear Wheelset	AM6	slugs	360	360	360
Distances:					
Front Left Centerplate Radius	P1	ft	0.75	0.75	0.75
Front Right Centerplate Radius	P2	ft	0.75	0.75	0.75
Rear Left Centerplate Radius	P3	ft	0.75	0.75	0.75
Rear Right Centerplate Radius	P4	ft	0.75	0.75	0.75
Front Left Side Bearing to Bolster Centerline	BE1	ft	2.083	2.083	2.083
Front Right Side Bearing to Bolster Centerline	BE2	ft	2.083	2.083	2.083
Rear Left Side Bearing to Bolster Centerline	BE3	ft	2.083	2.083	2.083
Rear Right Side Bearing to Bolster Centerline	BE4	ft	2.083	2.083	2.083
Front Left Spring to Bolster Center	G1	ft	3.29	3.29	3.29
Front Right Spring to Bolster Center	G2	ft	3.29	3.29	3.29
Rear Left Spring to Bolster Center	G3	ft	3.29	3.29	3.29
Rear Right Spring to Bolster Center	G4	ft	3.29	3.29	3.29
Front Left Half of Gage	W1	ft	2.375	2.375	2.375
Front Right Half of Gage	W2	ft	2.375	2.375	2.375

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
Rear Left Half of Gage	W3	ft	2.375	2.375	2.375
Rear Right Half of Gage	W4	ft	2.375	2.375	2.375
Front Wheelset c.g. to Front Left Side Spring	S1	ft	0.17	0.17	0.17
Front Wheelset c.g. to Front Right Side Spring	S2	ft	0.17	0.17	0.17
Rear Wheelset c.g. to Front Left Side Spring	S3	ft	0.17	0.17	0.17
Rear Wheelset c.g. to Front Right Side Spring	S4	ft	0.17	0.17	0.17
Heights: Front Left Side Bearing Clearance	ZB1	ft	0.021	0.021	0.021
Front Right Side Bearing Clearance	ZB2	ft	0.021	0.021	0.021
Rear Left Side Bearing Clearance	ZB3	ft	0.021	0.021	0.021
Rear Right Side Bearing Clearance	ZB4	ft	0.021	0.021	0.021
Front Left c.g. Wheelsets From Rail	C1	ft	1.5	1.5	1.5
Front Right c.g. Wheelsets From Rail	C2	ft	1.5	1.5	1.5
Rear Left c.g. Wheelsets From Rail	C3	ft	1.5	1.5	1.5
Rear Right c.g. Wheelsets From Rail	C4	ft	1.5	1.5	1.5
c.g. Bolster to c.g. Carbody Vertical Front	B1	ft	4.67	5.07	4.38
c.g. Bolster to c.g. Carbody Vertical Rear	B2	ft	4.67	5.07	4.38

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
c.g. Bolster to c.g. Carbody Longitudinal Front	D1	ft	15.26	14.23	14.20
c.g. Bolster to c.g. Carbody Longitudinal Rear	D2	ft	15.26	14.23	14.20
Front Left Gib Clearance	XSC1	ft	0.0313	0.0313	0.0313
Front Right Gib Clearance	XSC2	ft	0.0313	0.0313	0.0313
Rear Left Gib Clearance	XSC3	ft	0.0313	0.0313	0.0313
Rear Right Gib Clearance	XSC4	ft	0.0313	0.0313	0.0313
Front Left Flange Clearance	CW1	ft	0.0339	0.0339	0.0339
Front Right Flange Clearance	CW2	ft	0.0339	0.0339	0.0339
Rear Left Flange Clearance	CW3	ft	0.0339	0.0339	0.0339
Rear Right Flange Clearance	CW4	ft	0.0339	0.0339	0.0339
c.g. Front Body to c.g. Whole Body	D1PI	ft	9.74	10.78	10.8
c.g. Rear Body to c.g. Whole Body	D2PI	ft	9.74	10.78	10.8
II. INPUT CURVE PARAMETERS					
Speed	V	ft/sec	14.67-52.80	14.67-52.80	14.67-52.80
Rail Length	AL	ft	39.0	39.0	39.0
Max Crosslevel Difference	S	ft	0.0313	0.0313	0.0313

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
Truck Center Distance	D	ft	50.0	50.0	50.0
Wheel Base	B	ft	5.67	5.67	5.67
III. STIFFNESS PARAMETERS Front Left Centerplate Vertical	GKP_1	lb/ft	50,880,000	50,880,000	50,880,000
Front Right Centerplate Vertical	GKP_2	lb/ft	50,880,000	50,880,000	50,880,000
Rear Left Centerplate Vertical	GKP_3	lb/ft	50,880,000	50,880,000	50,880,000
Rear Right Centerplate Vertical	GKP_4	lb/ft	50,880,000	50,880,000	50,880,000
Front Left Side Bearing Vertical	$GKBE_1$	lb/ft	85,920,000	85,920,000	85,920,000
Front Right Side Bearing Vertical	$GKBE_2$	lb/ft	85,920,000	85,920,000	85,920,000
Rear Left Side Bearing Vertical	$GKBE_3$	lb/ft	85,920,000	85,920,000	85,920,000
Rear Right Side Bearing Vertical	$GKBE_4$	lb/ft	85,920,000	85,920,000	85,920,000
Corresponding Damping Type	$CDBE_{1,2,3,4}$	0 Viscous 1 Coulomb	0	0	0
Corresponding Damping Coefficient	$GDBE_{1,2,3,4}$	lbs/ft/sec or lbs	500	500	500
Front Left Suspension Vertical	GKG_1	lb/ft	563,789	563,789	563,789
Front Right Suspension Vertical	GKG_2	lb/ft	563,789	563,789	563,789
Rear Left Suspension Vertical	GKG_3	lb/ft	563,789	563,789	563,789
Rear Right Suspension Vertical	GKG_4	lb/ft	563,789	563,789	563,789

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
Corresponding Damping Type	$CDG_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	1
Corresponding Damping Coefficient	$GDG_{1,2,3,4}$	lbs or lbs/ft/sec	8,000	8,000	8,000
Front Left Suspension Lateral	GKS_1	lb/ft	257,960	257,960	257,960
Front Right Suspension Lateral	GKS_2	lb/ft	257,960	257,960	257,960
Rear Left Suspension Lateral	GKS_3	lb/ft	257,960	257,960	257,960
Rear Right Suspension Lateral	GKS_4	lb/ft	257,960	257,960	257,960
Corresponding Damping Type	$CDS_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	1
Corresponding Damping Coefficient	$GDS_{1,2,3,4}$	lbs or lbs/ft/sec	8,000	8,000	8,000
Front Left Track Vertical	GKW_1	lb/ft	6,000,000	6,000,000	6,000,000
Front Right Track Vertical	GKW_2	lb/ft	6,000,000	6,000,000	6,000,000
Rear Left Track Vertical	GKW_3	lb/ft	6,000,000	6,000,000	6,000,000
Rear Right Track Vertical	GKW_4	lb/ft	6,000,000	6,000,000	6,000,000
Corresponding Damping Type	$CDW_{1,2,3,4}$	0 Viscous 1 Coulomb	0	0	0
Corresponding Damping Coefficient	$GDW_{1,2,3,4}$	lbs/ft/sec	0.0	0.0	0.0
Front Left Track Lateral	$GKWX_1$	lb/ft	4,000,000	4,000,000	4,000,000
Front Right Track Lateral	$GKWX_2$	lb/ft	4,000,000	4,000,000	4,000,000

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
Rear Left Track Lateral	$GKWX_3$	lb/ft	4,000,000	4,000,000	4,000,000
Rear Right Track Lateral	$GKWX_4$	lb/ft	4,000,000	4,000,000	4,000,000
Corresponding Damping Type	$CDWX_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	1
Corresponding Damping Coefficient	$GDWX_{1,2,3,4}$	lbs or lbs/ft/sec	0.0	0.0	0.0
Tirsional Between Body Masses.	T12	ft/lbs/rad	1.48×10^6	1.48×10^6	1.48×10^6
Shearing Between Body of the Vertical Axis	B12Z	ft/lbs	0.0	0.0	0.0
Shearing Between Body in Lateral Direction	B12X	ft/lbs	0.0	0.0	0.0
Torsional Damping Between Bodies	D12	ft/lbs/rad/sec	0.0	0.0	0.0
Bending Between Bodies About Lateral Axis	T12X	ft/lbs/rad	4×10^9	4×10^8	4×10^8
Bending Between Bodies About Vertical Axis	T12Z	ft/lbs/rad	8×10^9	8×10^8	8×10^8
Length of Spring Travel	POGC	ft	0.26	0.26	0.26
Side Frame Lateral	SFLAT	lb/ft	2.0×10^6	2.0×10^6	2.0×10^6
Side Frame Vertical	SFVER	lb/ft	7.704×10^7	7.704×10^7	7.704×10^7
Friction Coefficient at Gib	COEFF	Dimensionless	0.3	0.3	0.3

VEHICLE NUMBER 39803

Description	Variable Name	Units	Validation	A	B
IV. MODEL TIME PARAMETERS					
Time Increment	DT	seconds	0.0005	0.0005	0.0005
Time Model to Pause	DTMAX	seconds	12	9	8
Number of Time Increments Between Printouts	NT	Dimensionless	100	100	100
V. MODEL MODE PARAMETERS					
Rolling Mode Flag	NRP	0 off 1 on			
Bouncing Mode Number of Joints	NDJ				

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
I. CAR DIMENSIONS Moments of Inertia:					
Front Mass Pitching	AIX1	$lb\text{-}ft\text{-}sec^2$	238,860	287,441	
Front Mass Rolling	AIY1	$lb\text{-}ft\text{-}sec^2$	76,824	166,816	
Front Mass Yawing	AIZ1	$lb\text{-}ft\text{-}sec^2$	217,752	244,866	
Rear Mass Pitching	AIX2	$lb\text{-}ft\text{-}sec^2$	238,860	287,441	
Rear Mass Rolling	AIY2	$lb\text{-}ft\text{-}sec^2$	76,824	166,816	
Rear Mass Yawing	AIZ2	$lb\text{-}ft\text{-}sec^2$	217,752	244,866	
Front Bolster Rolling	AIY3	$lb\text{-}ft\text{-}sec^2$	360	360	
Rear Bolster Rolling	AIY4	$lb\text{-}ft\text{-}sec^2$	360	360	
Front Wheelset/Frame Rolling	AIY5	$lb\text{-}ft\text{-}sec^2$	2,726	2,726	
Rear Wheelset/Frame Rolling	AIY6	$lb\text{-}ft\text{-}sec^2$	2,726	2,726	
Masses:					
Front Car Body	AM1	slugs	6,031	5,565	
Rear Car Body	AM2	slugs	6,031	5,565	
Front Bolster	AM3	slugs	144	144	
Rear Bolster	AM4	slugs	144	144	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
Front Wheelset	AM5	slugs	396	396	
Rear Wheelset	AM6	slugs	396	396	
Distances:					
Front Left Centerplate Radius	P1	ft	0.75	0.75	
Front Right Centerplate Radius	P2	ft	0.75	0.75	
Rear Left Centerplate Radius	P3	ft	0.75	0.75	
Rear Right Centerplate Radius	P4	ft	0.75	0.75	
Front Left Side Bearing to Bolster Centerline	BE1	ft	2.083	2.083	
Front Right Side Bearing to Bolster Centerline	BE2	ft	2.083	2.083	
Rear Left Side Bearing to Bolster Centerline	BE3	ft	2.083	2.083	
Rear Right Side Bearing to Bolster Centerline	BE4	ft	2.083	2.083	
Front Left Spring to Bolster Center	G1	ft	3.29	3.29	
Front Right Spring to Bolster Center	G2	ft	3.29	3.29	
Rear Left Spring to Bolster Center	G3	ft	3.29	3.29	
Rear Right Spring to Bolster Center	G4	ft	3.29	3.29	
Front Left Half of Gage	W1	ft	2.375	2.375	
Front Right Half of Gage	W2	ft	2.375	2.375	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
Rear Left Half of Gage	W3	ft	2.375	2.375	
Rear Right Half of Gage	W4	ft	2.375	2.375	
Front Wheelset c.g. to Front Left Side Spring	S1	ft	0.17	0.17	
Front Wheelset c.g. to Front Right Side Spring	S2	ft	0.17	0.17	
Rear Wheelset c.g. to Front Left Side Spring	S3	ft	0.17	0.17	
Rear Wheelset c.g. to Front Right Side Spring	S4	ft	0.17	0.17	
Heights: Front Left Side Bearing Clearance	ZB1	ft	0.021	0.021	
Front Right Side Bearing Clearance	ZB2	ft	0.021	0.021	
Rear Left Side Bearing Clearance	ZB3	ft	0.021	0.021	
Rear Right Side Bearing Clearance	ZB4	ft	0.021	0.021	
Front Left c.g. Wheelsets From Rail	C1	ft	1.5	1.5	
Front Right c.g. Wheelsets From Rail	C2	ft	1.5	1.5	
Rear Left c.g. Wheelsets From Rail	C3	ft	1.5	1.5	
Rear Right c.g. Wheelsets From Rail	C4	ft	1.5	1.5	
c.g. Bolster to c.g. Carbody Vertical Front	B1	ft	4.95	4.73	
c.g. Bolster to c.g. Carbody Vertical Rear	B2	ft	4.95	4.73	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
c.g. Bolster to c.g. Carbody Longitudinal Front	D1	ft	16.53	15.8	
c.g. Bolster to c.g. Carbody Longitudinal Rear	D2	ft	16.53	15.8	
Front Left Gib Clearance	XSC1	ft	0.0313	0.0313	
Front Right Gib Clearance	XSC2	ft	0.0313	0.0313	
Rear Left Gib Clearance	XSC3	ft	0.0313	0.0313	
Rear Right Gib Clearance	XSC4	ft	0.0313	0.0313	
Front Left Flange Clearance	CW1	ft	0.0339	0.0339	
Front Right Flange Clearance	CW2	ft	0.0339	0.0339	
Rear Left Flange Clearance	CW3	ft	0.0339	0.0339	
Rear Right Flange Clearance	CW4	ft	0.0339	0.0339	
c.g. Front Body to c.g. Whole Body	D1PI	ft	6.47	7.2	
c.g. Rear Body to c.g. Whole Body	D2PI	ft	6.47	7.2	
II. INPUT CURVE PARAMETERS Speed	V	ft/sec	14.67 - 52.8	14.67 - 52.8	
Rail Length	AL	ft	39.0	39.0	
Max Crosslevel Difference	S	ft	0.0313	0.0313	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
Truck Center Distance	D	ft	46.0	46.0	
Wheel Base	B	ft	5.67	5.67	
III. STIFFNESS PARAMETERS Front Left Centerplate Vertical	GKP_1	lb/ft	50,880,000	50,880,000	
Front Right Centerplate Vertical	GKP_2	lb/ft	50,880,000	50,880,000	
Rear Left Centerplate Vertical	GKP_3	lb/ft	50,880,000	50,880,000	
Rear Right Centerplate Vertical	GKP_4	lb/ft	50,880,000	50,880,000	
Front Left Side Bearing Vertical	$GKBE_1$	lb/ft	85,920,000	85,920,000	
Front Right Side Bearing Vertical	$GKBE_2$	lb/ft	85,920,000	85,920,000	
Rear Left Side Bearing Vertical	$GKBE_3$	lb/ft	85,920,000	85,920,000	
Rear Right Side Bearing Vertical	$GKBE_4$	lb/ft	85,920,000	85,920,000	
Corresponding Damping Type	$CDBE_{1,2,3,4}$	0 Viscous 1 Coulomb	0	0	
Corresponding Damping Coefficient	$GDBE_{1,2,3,4}$	lbs/ft/sec or lbs	500	500	
Front Left Suspension Vertical	GKG_1	lb/ft	563,789	563,789	
Front Right Suspension Vertical	GKG_2	lb/ft	563,789	563,789	
Rear Left Suspension Vertical	GKG_3	lb/ft	563,789	563,789	
Rear Right Suspension Vertical	GKG_4	lb/ft	563,789	563,789	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
Corresponding Damping Type	$CDG_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	
Corresponding Damping Coefficient	$GDG_{1,2,3,4}$	lbs or lbs/ft/sec	8,000	8,000	
Front Left Suspension Lateral	GKS_1	lb/ft	257,960	257,960	
Front Right Suspension Lateral	GKS_2	lb/ft	257,960	257,960	
Rear Left Suspension Lateral	GKS_3	lb/ft	257,960	257,960	
Rear Right Suspension Lateral	GKS_4	lb/ft	257,960	257,960	
Corresponding Damping Type	$CDS_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	
Corresponding Damping Coefficient	$GDS_{1,2,3,4}$	lbs or lbs/ft/sec	8,000	8,000	
Front Left Track Vertical	GKW_1	lb/ft	6,000,000	6,000,000	
Front Right Track Vertical	GKW_2	lb/ft	6,000,000	6,000,000	
Rear Left Track Vertical	GKW_3	lb/ft	6,000,000	6,000,000	
Rear Right Track Vertical	GKW_4	lb/ft	6,000,000	6,000,000	
Corresponding Damping Type	$CDW_{1,2,3,4}$	0 Viscous 1 Coulomb	0	0	
Corresponding Damping Coefficient	$GDW_{1,2,3,4}$	lbs/ft/sec	0.0	0.0	
Front Left Track Lateral	$GKWX_1$	lb/ft	4,000,000	4,000,000	
Front Right Track Lateral	$GKWX_2$	lb/ft	4,000,000	4,000,000	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
Rear Left Track Lateral	$GKWX_3$	lb/ft	4,000,000	4,000,000	
Rear Right Track Lateral	$GKWX_4$	lb/ft	4,000,000	4,000,000	
Corresponding Damping Type	$CDWX_{1,2,3,4}$	0 Viscous 1 Coulomb	1	1	
Corresponding Damping Coefficient	$GDWX_{1,2,3,4}$	lbs or lbs/ft/sec	0.0	0.0	
Tirsional Between Body Masses	T12	ft/lbs/rad	1.48×10^8	1.48×10^8	
Shearing Between Body of the Vertical Axis	B12Z	ft/lbs	0.0	0.0	
Shearing Between Body in Lateral Direction	B12X	ft/lbs	0.0	0.0	
Torsional Damping Between Bodies	D12	ft/lbs/rad/sec	0.0	0.0	
Bending Between Bodies About Lateral Axis	T12X	ft/lbs/rad	4.0×10^8	4.0×10^8	
Bending Between Bodies About Vertical Axis	T12Z	ft/lbs/rad	8.0×10^8	8.0×10^8	
Length of Spring Travel	POGC	ft	0.255	0.255	
Side Frame Lateral	SFLAT	lb/ft	2,000,000	2,000,000	
Side Frame Vertical	SFVER	lb/ft	77,040,000	77,040,000	
Friction Coefficient at Gib	COEFF	Dimensionless	0.3	0.3	

VEHICLE NUMBER 39837

Description	Variable Name	Units	Validation	A	B
IV. MODEL TIME PARAMETERS					
Time Increment	DT	seconds	0.0005	0.0005	
Time Model to Pause	DTMAX	seconds	16	16	
Number of Time Increments Between Printouts	NT	Dimensionless	100	100	
V. MODEL MODE PARAMETERS					
Rolling Mode Flag	NRP	0 off 1 on			
Bouncing Mode Number of Joints	NDJ				

APPENDIX E

ANALYSIS OF
NUMERICAL INTEGRATION ERROR

ANALYSIS OF NUMERICAL INTEGRATION ERROR

Two important factors to be addressed when numerically integrating a set of differential equations are the order of the integration and the size of the integration step. The AAR rock and roll model discussed in this report originally used a fourth order Runge-Kutta numerical integration technique. This fourth order integration method requires four evaluations of the derivatives of the dependent variables for each integration step. For the suggested 0.00025 second integration step size, 4,000 evaluations of the derivatives were required per second of simulated time. These evaluations required 20 minutes of computer time per second of simulated time on the microcomputer used in this study. For the purpose of this study, a considerable reduction in the computer time needed to simulate vehicle response was required.

To decrease the computer time requirements, either the integration step size must be increased, the order of integration must be reduced or a combination of these changes must be implemented. The methodology for selecting optimum values for the integration step size and order of the integration technique must provide criteria for trading-off the errors associated with longer integration step size and/or lower orders of integration with the cost and time associated with the integration process. These criteria should be based on the intended use of the data generated by the computer program.

The first step in establishing the criteria was to review the physics of the rock and roll phenomena to determine the importance of the integration step size. Rock and roll behavior is observed mainly on staggered, bolted rail producing a combined lateral and rolling motion of the carbody at a frequency of approximately 1 hertz. It would appear that an integration step size of 0.01 second would be more than adequate if the predominate frequency was 1 hertz. However, while this is generally true for the carbody, significant high frequency events associated with the truck bolster are present and must be accounted for in the simulation. The high frequency events associated with the impact of the bolster with the truck side frame, the impact of the carbody with the side bearings, and the rocking of the carbody on the centerplate, are of relatively short duration (on the order of several milliseconds). Therefore, an integration step size of 0.0005 second was used to include the important high frequency interactions between the vehicle subsystems. Changes in the carbody roll angle, the amount of wheel lift and the lateral acceleration of the carbody with integration step size and integration order were considered to be of major importance, since the descriptors used to characterize the vehicle response were peak values of these variables.

The developed methdology estimated the error associated with the integration technique by simulating 12 seconds of vehicle response and observing the peak value of wheel lift, carbody roll angle and carbody lateral accelerations. The results indicate a change of less than two percent in these variables when the step size was doubled and the integration technique decreased to second order. This error was judged acceptable in light of the uncertainty (approximately 10 percent or more) of the model input parameters.

Further increasing the step size or decreasing the order of integration lead to instability in the integration techniques. This instability was related to impact phenomena associated with the bolster and with the large numerical value of the stiffness constant used to model these impacts.

These modifications resulted in a reduction in computer time use by approximately a factor of four. This factor is the combination of a reduction of two associated with integration step size and an additional factor of two associated with the order of numerical integration. In terms of computer time, a 12 second simulation of the vehicle dynamics required approximately one hour of computer time or one second of simulation required five minutes of computer time instead of the 20 minutes it originally required. For the minicomputer used in the study, the total cost of running the simulations was less than $50.00 for twelve seconds of simulation time.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-621-652/988

Mathematical Modeling of Dodx Railcars,
1980
US DOT, FRA